What drives the term structure in the Euro area? Evidence from a model with feedback

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Abstract

I study a general-equilibrium model of the term structure where bond prices are an integral part of the monetary transmission mechanism. The model is estimated on quarterly Euro area data. I show that, besides shocks to the inflation target, also exogenous variations in money demand and bond supply can explain movements in long-term interest rates. I also find that taking into account the impact of bond yields on the macroeconomy generates superior in-sample and out-of-sample forecasts for output, inflation and for bond yields.

KEYWORDS: Monetary policy, yield curve, monetary transmission mechanism.

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> "*In a world involving no transaction friction and no uncertainty, there would be no reason for a spread between the yield on any two assets, and hence there would be no difference in the yield on money and on securities. (...) In such a world securities themselves would circulate as money and be acceptable in transactions; demand bank deposits would bear interest, just as they did in this country in the period of the twenties.*"
>
> Samuelson (1947)

1 Introduction

Central banks have traditionally argued for the importance of understanding the determinants of the term structure of interest rates. The reason is that the term structure plays a key role in the monetary transmission mechanism. For instance, on September 14, 2005, during a Testimony before the Committee on Economic and Monetary Affairs of the European Parliament, Jean-Claude Trichet, president of the European Central Bank, suggested that

> "*(...) investment should benefit from the exceptionally low level of both nominal and real market interest rates prevailing across the entire maturity spectrum.*"

This is indicative of the conventional wisdom that, by affecting the term structure, a central bank can control part of the monetary transmission mechanism. The effects of monetary policy on long-term interest rates operate partly through changes in expectations about future monetary policy, and partly through movements in term premia. Disentangling the nature of the transmission of the transmission of monetary policy through bond yields can also help central bankers to figure out the appropriate policy response to exogenous shocks. Bernanke (2006) proposed the view that

> "*(...) if spending depends on long-term interest rates, special factors that lower the spread between short-term and long-term rates will stimulate aggregate demand. Thus, when the term premium declines, a higher short-term rate is required to obtain the long-term rate and the overall mix of financial conditions consistent with maximum sustainable employment and stable prices.*"

The interest of policymakers in the movements of the term structure is mirrored by the large attention that academic research that has recently devoted to this topic. Empirical 'macro finance' models that study the joint dynamics of the bond yields and the macroeconomy (e.g. see Ang and Piazzesi, 2003) have been developed along with more structural frameworks that exploit the term structure implications of standard New Keynesian models (e.g. see Rudebusch and Wu, 2003 and Hördahl, Tristani and Vestin, 2006).[1]

[1]See Diebold, Piazzesi, and Rudebusch (2005) and Rudebusch, Sack, and Swanson (2007) for comprehensive overviews of the literature.

A common strategy in most of the available contributions in the macro-finance field consists in pricing the term structure by using the kernel for one period bonds. Since the kernel is extracted from the solution of the model economy, this pricing strategy ignores the issue of the 'feedback' from bond yields to the macroeconomy stressed by the policymakers. While the these models imply effects of monetary policy and the macroeconomy on the term structure, they do not feature effects in the opposite direction, from the term structure (and term premia) to the macroeconomy and monetary policy. After providing empirical evidence in favour of this feedback for the U.S. economy, Marzo, Söderström and Zagaglia (2008) draw on the framework of Andrés, López-Salido and Nelson (2004) to propose a dynamic stochastic general equilibrium (DSGE) model where bond yields affect the dynamics of the macroeconomic variables.

In this paper, I use an estimated version of the model of Marzo, Söderström and Zagaglia (2008) to study the macroeconomic determinants of bond yields in the Euro area. The framework of Marzo, Söderström and Zagaglia (2008) builds on the portfolio approach of Tobin (1969, 1982) to introduce segmentation in financial markets. Due to frictions that makes changes in bond holdings costly to households, the model generates positive holdings of different types of bonds in equilibrium. In this paper, I use a version of the model with short, medium and long-term bonds. I assume that changing the ratios between the bond and money holdings generates a real cost for the household.[2] The maturity profile of bonds is then determined by the propensity of households to reallocate resources between each bond and money. This mechanism creates a link between monetary aggregates and bond prices, and allows to study the role of money demand shocks when bond prices matter for the macroeconomy.

I enrich the model of Marzo, Söderström and Zagaglia (2008) by introducing a time-varying inflation target in the monetary policy rule, price and wage indexation and a more complete stochastic structure. The first feature is consistent with the downward trend in inflation over the sample that is typically related to changes in the inflation target (see Gurkaynak, Sack and Swanson, 2005), and has been adopted in De Graeve, Emiris and Wouters (2009) and Doh (2008). Wage and price stickiness from quadratic adjustment costs include partial indexation to the central bank's inflation target, like in Ireland (2007). I estimate and evaluate the model on quarterly Euro area using standard Bayesian methods along the lines of Adolfson et al. (2007) and Smets and Wouters (2003, 2004).

The contribution of this paper is related to the recent works of De Graeve, Emiris and Wouters (2009), Doh (2008) and Amisano and Tristani (2008). The former augment the loglinearized model of Smets and Wouters (2003) with model-consistent yields for longer maturities. In the Bayesian estimation, they introduce measurement errors in the yields to mimic term premia. Doh (2008) estimates the second-order Taylor approximation of a

[2] King and Thomas (2008) introduce money market segmentation by endogenizing the distribution of money balances. Although their approach opens the black box of adjustment costs used in this paper, it stresses the same role of money balances for transaction purposes.

small-scale New Keynesian model with conditional heteroskedasticity of the structural shocks. Amisano and Tristani (2008) augment the second-order approximation of a small structural model with regime switching in the shocks.

The approach followed in this paper differs from that of the available literature along two dimensions. First, whereas most of the results are available for the U.S. economy, I focus on the Euro area. Furthermore, my model includes a full-fledged feedback from bond yield. In contrast to my model, the contribution of De Graeve, Emiris and Wouters (2009) does not feature a feedback from the term structure to the macroeconomy. The use of a second-order approximation in Doh (2008) and Amisano and Tristani (2008) implies that the variances of the structural shocks determine the solution of the model. This means that the market source of risk affects the laws of motion of inflation and output. However, the conditional mean of the term structure yields is extracted from the model solution using the one-period pricing kernel. As a result, the conditional mean of long-term rates does not matter for inflation and output fluctuations, whereas the market source of risk does.

This paper presents two main results. I show that my model captures the role of the role assigned by Smets and Wouters (2003) to productivity, labour supply and monetary policy shocks for the dynamics of real variables. Consistently with De Graeve, Emiris and Wouters (2009), shocks to monetary policy and to the inflation target explain a large fractions of the yields. However, I also find that shocks to both money demand and the supply of bonds play an important role in explaining the dynamics of bond yields of the Euro area. This is a novel finding that is potentially relevant for the current policy environment of the Euro area. In March 2009, during a speech at the European Business Forum, Lucas Papademos, vice president of the ECB, has suggested that

> "*(...) non-standard measures aimed at reducing funding uncertainty and enhancing the functioning of the credit market and, consequently, the monetary policy transmission mechanism, my represent possible courses of action.*"

Acknowledging the role of bond supply and money demand shocks for term structure changes lays the ground for understanding the mechanics of 'quantitative easing', namely asset purchases by central banks that aim at lowering long-term interest rates. Finally, in the evaluation of the framework, I also show that the estimated model forecasts output and inflation better than a standard New Keynesian model both in-sample and out-of-sample. The model also provides better forecasts for medium and long-term yields than vector autoregressions and Bayesian vector autoregressions models at long horizons.

The paper is organized as follows. Section 2 outlines the model. Section 3 discusses the dataset used for the estimation, the calibrated parameters, the calculation of the deterministic steady state, and the prior assumptions. In Section 4 I comment on the parameter estimates and the model fit. Section 5 I provides insights into the the role of the bond and money market frictions. Section 6 concludes the discussion.

2 The model

In this section, I develop a business cycle model with an endogenous term structure of interest rates, which is an integral part of the transmission of monetary policy. The starting point for our analysis is a New-Keynesian model with sticky prices, habits in consumption, and capital adjustment costs. To this model I add an endogenous term structure of interest rates by assuming that households allocate their assets among three different types of bonds, which I interpret as being of different maturity: short-term money market bonds, medium-term bonds, and long-term bonds. As households are assumed to face costs when adjusting their bond holdings, there is a non-zero demand for each type of bond, and the expectations hypothesis does not hold. Households also face transaction costs for money holdings, so the effect of term structure movements operate through households' money demand.

2.1 Households

There is a continuum of identical and infinitely-lived households indexed by $i \in [0, 1]$. (For convenience I omit the index i in what follows.) These households obtain utility from consumption of a bundle c_t of differentiated goods relative to an endogenous habit level, real money holdings M_t/P_t, and disutility from labor ℓ_t according to the utility function

$$U\left(c_t, c_{t-1}, \frac{M_t}{P_t}, \ell_t\right) = \mathsf{E}_0 \sum_{t=0}^{\infty} \beta^t \epsilon_t^p \left[\frac{1}{1-1/\sigma}\left(c_t - \gamma c_{t-1}\right)^{1-1/\sigma} + \epsilon_t^m \frac{\Lambda}{1-\chi}\left(\frac{M_t}{P_t}\right)^{1-\chi} - \epsilon_t^\ell \frac{\Psi}{1+1/\psi}\ell_t^{1+1/\psi}\right], \quad (1)$$

where β is a discount factor. c_t is a constant elasticity of substitution aggregator of differentiated goods:

$$c_t = \left[\int_0^1 c_t(j)^{(\theta_{f,t}-1)/\theta_{f,t}} dj\right]^{\theta_{f,t}/(\theta_{f,t}-1)}, \quad (2)$$

σ determines the elasticity of intertemporal substitution, γ determines the importance of habits, χ is the elasticity of money demand, ψ is the elasticity of labor supply, and $\theta_{f,t}$ denotes a time-varying elasticity of substitution across across varieties of goods. The preference shocks ϵ_t^ι for $\iota = \{p, m, \ell\}$ are autoregressive shocks

$$\ln(\epsilon_t^\iota) = \rho_\iota \ln(\epsilon_{t-1}^\iota) + \nu_t^\iota. \quad (3)$$

Households allocate their wealth among money holdings, accumulation of capital, which is rented to firms, and holdings of three types of nominal bonds. I interpret these different bonds as short-term money market bonds (denoted B_t), medium-term ($b_{M,t}$), and long-term bonds ($B_{L,t}$), which pay the returns R_t and $R_{L,t}$, respectively.

In order to obtain a realistic internal propagation mechanism in the model, and to generate fluctuations of the rental rate of capital compatible with the empirical evidence, we introduce quadratic adjustment costs of investment along the lines of Abel and Blanchard (1983) and Kim (2000). Thus,

$$AC_t^i = \frac{\phi_K}{2}\left(\frac{i_t}{i_{t-1}}\right)^2, \tag{4}$$

where k_t and i_t are, respectively, the levels of real capital and investment. The law of motion of the capital stock is given by

$$k_{t+1} = \epsilon_t^i \left(1 - AC_t^i\right) i_t + (1-\delta)k_t, \tag{5}$$

where δ is the depreciation rate of the capital stock, and ϵ_t^i is a shock to the relative price of investment goods

$$\ln(\epsilon_t^i) = \rho_i \ln(\epsilon_{t-1}^i) + \nu_t^i \tag{6}$$

with a white noise ν_t^i.

The representative household maximizes its life-time utility U_t subject to the budget constraint

$$\begin{aligned}\frac{C_t}{P_t} + \frac{I_t}{P_t} + AC_t^W + \tau_t + \frac{B_t}{P_t} + \frac{B_{M,t}}{P_t}\left(1 + AC_t^M\right) + \frac{B_{L,t}}{P_t}\left(1 + AC_t^L\right) + \frac{M_t}{P_t}\left(1 + AC_t^m\right)\\ = R_{t-1}\frac{B_{t-1}}{P_t} + R_{M,t-1}\frac{B_{M,t-1}}{P_t} + R_{L,t-1}\frac{B_{L,t-1}}{P_t} + \frac{M_{t-1}}{P_t} + \frac{W_t}{P_t}\ell_t + \frac{Q_t}{P_t}k_t + \Omega_t,\end{aligned} \tag{7}$$

where the AC_t^ι terms are different adjustment costs, to be specified below, P_t is the aggregate price level, and I_t is investment. The household obtains income from renting capital, k_t, to firms at the rental rate q_t, labour services, $w_t\ell_t$, where w_t is the real wage, and from its share in firms' real profits, Ω_t. Finally, households pay a real lump-sum tax τ_t.

2.1.1 Household's portfolio

According to the traditional asset allocation theory, agents hold different types of assets in their portfolio depending on each asset's risk/return trade-off and expectations about the future path of this trade-off. For government bonds, the risk element is exclusively related to the uncertainty with respect to the future path of returns. The main difficulty when modelling assets with different rates of return in general equilibrium is due to the solution technique employed which, for computational reasons, typically involves Taylor approximations (up to first or second order) of the system of equations around the steady state. Of course, this procedure eliminates any role for higher-order terms, making it difficult to allow a full portfolio choice on the basis of the risk/return trade-off. I instead implement an alternative methodology that allows for the simultaneous presence of different rates of return on government bonds.

To ensure a non-zero demand for each bond, I follow Andrés, López-Salido and Nelson (2004) and generalize the Tobin (1969, 1982) model of portfolio allocation by inserting a set of portfolio adjustment frictions, which can be rationalized as transaction costs. I assume that bond trading is costly to each agent, and, in particular, that bond adjustment costs are quadratic and given by

$$AC_t^L = \frac{\phi_L}{2}\left(\frac{B_{L,t}/P_t}{B_{L,t-1}/P_{t-1}}\right)^2 y_t, \tag{8}$$

The adjustment cost is paid in terms of aggregate output y_t, an assumption that allows us to better quantify the magnitude of these costs in terms of the budget for the representative household, and also implies that spreads between the different bonds returns vary over time. In steady state, as long as $\phi_L \neq 0$ these adjustment costs are non-zero.

Furthermore, in order to capture the entire dimension of costs involved in any financial transaction, I also assume transaction costs for money holdings. Since short-term bonds are money-market instruments, they are perfect substitute for money. This does not hold for the other types of bonds. The idea is to capture the risk propensity of households through the willingness to 'liquidate' a bond. Ideally, the larger the substitutability between long-term bonds and money, the more the households are willing to reallocate resources into money, and the larger the liquidity services that households can potentially use to smooth out consumption in each period.

The relationship of imperfect substitutability between money and money is formalized in the transaction cost function

$$AC_t^{\iota,m} = \frac{v_\iota}{2}\left(\frac{M_t/B_{\iota,t}}{M/B_\iota} - 1\right)^2 y_t, \tag{9}$$

The adjustment-cost function (9) implies that changes of bond holdings affect the money market as they generate movements in money demand. When there is an increase in the desired stock of a bond, households' demand for money increases in order to keep the money-bond ratio constant. This implies that the degree of imperfect substitutability between money and bonds affects the yields.

The economic justification for the adjustment costs between bonds and money relies in the fact that we can think of the liquidity profile as a proxy for the behavior of agents towards risk (see Tobin, 1958). Since bonds are implicitly held until expiry in our model, the longer the maturity of a bond, the more limited its capability of providing opportunities for consumption smoothing until expiry, should negative shocks occur. This indicates that the household has a larger propensity to reallocate between bonds and money for bonds with longer maturities. In terms of priors on the parameters, the theory suggests v_L/v_M.

The adjustment costs are paid in terms of real output y_t, and they measure the amount of resources spent in order to shift the portfolio allocation between money and bonds at long maturities. Finally, the money/bond transaction costs are present only during the transition to the long-run equilibrium, and are zero at the steady state. Consequently, only the bond adjustment costs are present in steady state, and are therefore responsible for the different long-run rates of return.

2.1.2 Labour supply decision

Each household is a monopolistic supplier of an idiosyncratic labor service ℓ_{jt} indexed by j over a set m. Heterogenous labor inputs for the production of intermediate goods aggregate

$$\ell_t \leq \left[\int_{j \in m} \ell_{jt}^{\frac{1-\theta_{\ell,t}}{\theta_{\ell,t}}} dj \right]^{\frac{\theta_{\ell,t}}{1-\theta_{\ell,t}}}. \tag{10}$$

The elasticity of substitution across labor services $\theta_{\ell,t} > 1$ varies around a mean θ_ℓ

$$\theta_{\ell,t} := \theta_\ell + \epsilon_t^w \tag{11}$$

where ϵ_t^w is an autocorrelated shock to wage markups with variance σ_w.

Differentiation in the labor market is due to the decreasing marginal productivity of labor. Since firms take the price of labor as given, the demand function for labor is

$$\ell_{jt} = \left[\frac{w_{jt}}{w_t} \right]^{-\theta_{\ell,t}} \ell_t \tag{12}$$

where w_{jt} is the real wage paid to household j. The wage index w_t prevailing in the economy takes the standard form:

$$w_t = \left[\int_{j \in m} w_{jt}^{1-\theta_{\ell,t}} dj \right]^{\frac{1}{1-\theta_{\ell,t}}} \tag{13}$$

Household j chooses the nominal wage rate for his idiosyncratic labor service. Since there is a large number of workers, each wage setter takes both w_t and ℓ_t as given. In order to mimic wage stickiness, I assume the presence of quadratic adjustment costs for nominal wages:

$$AC_t^W = \frac{\phi_w}{2} \left(\frac{W_{jt}}{W_{jt-1}} - \gamma_W \pi_t^* - (1-\gamma_W)\pi_{t-1} \right)^2 W_t \tag{14}$$

This specification is in the spirit of the literature on staggered wage contracts initiated by Rotemberg (1982). An alternative modelling approach refers to the Calvo (1983)-style setting originally conceived for price stickiness, and adapted to staggered wages in Christiano, Eichenbaum, and Evans (2005). Since these two settings are substantially equivalent for a loglinearized model, the choice of the pricing scheme is irrelevant for the purpose of this paper. Equation 14 formalizes the idea that persistent deviations of the rate of change of nominal wages from an index of wage inflation are costly. I assume that the latter equals a weighted average of the central bank's inflation target π_t^*, and previous period's inflation. This formulation is also adopted in Ireland (2007), as well as in De Graeve, Emiris and Wouters (2009). The adjustment cost is expressed in units of nominal wages.

2.1.3 Optimality conditions

The optimal intra-temporal consumption choice implies the typical demand function

$$\frac{c_t(j)}{c_t} = \left[\frac{P_t(j)}{P_t}\right]^{-\theta_{f,t}}, \tag{15}$$

where P_t is the aggregate price index

$$P_t = \left[\int_0^1 (P_t(j))^{1-\theta_{f,t}}\, dj\right]^{1/(1-\theta_{f,t})}. \tag{16}$$

The elasticity of substitution of demand $\theta_{f,t}$ between intermediate goods is time-varying around a mean θ_f

$$\theta_{f,t} := \theta_f + \epsilon_t^P \tag{17}$$

where ϵ_t^P is an autocorrelated shock to price markups with variance σ_P.

Maximizing life-time utility in equation (1) subject to the budget constraint (7), and imposing symmetry of choices imply that the optimal inter-temporal consumption choice satisfies

$$\epsilon_t^p (c_t - \gamma c_{t-1})^{-1/\sigma} - \beta\gamma \mathsf{E}_t \epsilon_{t+1}^p (c_{t+1} - \gamma c_t)^{-1/\sigma} = \lambda_t, \tag{18}$$

where λ_t is the marginal utility of consumption; the optimal wage choice follows from

$$\begin{aligned}\epsilon_t^\ell \Psi \frac{\theta_{\ell,t}}{w_t}(\ell_t)^{1+1/\psi} - \lambda_t \left[\phi_w\left(\frac{w_t}{w_{t-1}}\pi_t - \gamma_W \pi_t^* - (1-\gamma_W)\pi_{t-1}\right)\frac{w_t}{w_{t-1}}\pi_t - (1-\theta_{\ell,t})\ell_t\right] \\ + \beta \mathsf{E}_t \lambda_{t+1}\phi_w\left(\frac{w_{t+1}}{w_t}\pi_{t+1} - \gamma_W \pi_{t+1}^* - (1-\gamma_W)\pi_t\right)\left(\frac{w_{t+1}}{w_t}\right)^2 \pi_{t+1} = 0,\end{aligned} \tag{19}$$

holdings of the money market bond follow

$$\beta \mathsf{E}_t \frac{R_t \lambda_{t+1}}{\pi_{t+1}} = \lambda_t; \tag{20}$$

and holdings of the remaining two bonds satisfy

$$\beta \mathsf{E}_t \frac{R_{\iota,t}\lambda_{t+1}}{\pi_{t+1}} + \beta\phi_\iota \mathsf{E}_t \left\{ \lambda_{t+1} \left(\frac{b_{\iota,t+1}}{b_{\iota,t}} \right)^3 y_{t+1} \right\}$$

$$= \lambda_t \left[1 + \frac{3}{2}\phi_\iota \left(\frac{b_{\iota,t}}{b_{\iota,t-1}} \right)^2 y_t - v_\iota \kappa_\iota \left(\frac{m_t}{b_{\iota,t}} \right)^2 \left(\frac{m_t}{b_{\iota,t}}\kappa_\iota - 1 \right) \right], \tag{21}$$

for $\iota = M, L$, where $m_t = M_t/P_t$ are real money holdings, $b_{\iota,t} = B_{\iota,t}/P_t$ are real holdings of bond ι, and $\pi_t = P_t/P_{t-1}$ is the gross rate of inflation; Note that in the case without bond adjustment and transaction costs ($\phi_\iota = v_\iota = \kappa_\iota = 0$) the optimality conditions for the three bonds are identical, so all bonds give the same return. The different returns of the bonds thus arise from the presence of adjustment and transaction costs. Optimal money holdings evolve according to

$$\Lambda \epsilon_t^m m_t^{-\chi} + \beta \mathsf{E}_t \frac{\lambda_{t+1}}{\pi_{t+1}} = \tag{22}$$

$$\lambda_t \left[1 + AC_t^{S,m} + AC_t^{L,m} \right] \tag{23}$$

$$+\lambda_t m_t \left[v_M \kappa_S \left(\frac{m_t}{b_{M,t}}\kappa_S - 1 \right) \frac{y_t}{b_{M,t}} + v_L \kappa_L \left(\frac{m_t}{b_{L,t}}\kappa_L - 1 \right) \frac{y_t}{b_{L,t}} \right],$$

The first-order conditions for the capital stock and investment are

$$\beta (1-\delta) \mathsf{E}_t \mu_{t+1} = \mu_t - \lambda_t q_t, \tag{24}$$

$$\mu_t \epsilon_t^i + \beta \mathsf{E}_t \mu_{t+1} \epsilon_{t+1}^i \phi_K \left(\frac{i_{t+1}}{i_t} \right)^3 = \lambda_t + \mu_t \epsilon_t^i \frac{3}{2} \phi_K \left(\frac{i_t}{i_{t-1}} \right)^2 \tag{25}$$

where μ_t is the marginal value of capital.

2.2 Firms

Firms (indexed by $j \in [0,1]$) produce and sell differentiated final goods in a monopolistically competitive market. These goods are produced using capital and labor following the Cobb-Douglas production function

$$y_t(j) = \epsilon_t^a \left[k_t(j) \right]^\alpha \left[\ell_t(j) \right]^{1-\alpha} - \Phi, \tag{26}$$

where a_t is a technology process given by

$$\ln\left(\epsilon_t^a\right) = \rho_a \ln\left(\epsilon_{t-1}^a\right) + \nu_t^a \tag{27}$$

Φ is a fixed cost to ensure that profits are zero in steady state, and ν_t^a is an i.i.d. shock with zero mean and constant variance σ_a^2.

Firms set prices to maximize the expected future stream of profits subject to a quadratic price adjustment cost, following Rotemberg (1982).[3] The price-adjustment cost function AC_t^P takes the form

$$AC_t^P = \frac{\phi_P}{2}\left(\frac{P_t}{P_{t-1}} - \gamma_P \pi_t^* - (1-\gamma_P)\pi_{t-1}\right)^2 y_t, \tag{28}$$

so price changes are costly as they deviate from a weighted average of steady state inflation and previous period's inflation.

The presence of price adjustment costs implies that the firm's price-setting problem is dynamic. The expected future profit stream is evaluated through a stochastic pricing kernel for contingent claims ρ_t, which plays the role of the firms' discount factor. However, assuming that each agent has access to a complete set of markets for contingent claims, the discount factors of firms and households are equal:

$$\mathsf{E}_t \frac{\rho_{t+1}}{\rho_t} = \beta \mathsf{E}_t \frac{\lambda_{t+1}}{\lambda_t}. \tag{29}$$

Each firm chooses its production inputs to maximize profits subject to the production function (26). The first-order conditions with respect to capital and labor are then given by

$$q_t = \alpha\left(1 - \frac{1}{e_t^y}\right)\left(\frac{y_t + \Phi}{k_t}\right), \tag{30}$$

$$w_t = (1-\alpha)\left(1 - \frac{1}{e_t^y}\right)\left(\frac{y_t + \Phi}{\ell_t}\right), \tag{31}$$

where we have omitted the index j and where e_t^y denotes the output demand elasticity, determined by

$$\begin{aligned}\frac{1}{e_t^y} = \frac{1}{\theta_{f,t}}\Bigg\{ & 1 - \phi_P\left(\pi_t - \gamma_P \pi_t^* - (1-\gamma_P)\pi_{t-1}\right)\pi_t \\ & + \beta\phi_P \mathsf{E}_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\pi_{t+1} - \gamma_P \pi_{t+1}^* - (1-\gamma_P)\pi_t\right)\pi_{t+1}^2 \frac{y_{t+1}}{y_t}\right]\Bigg\}.\end{aligned} \tag{32}$$

Equation (32) measures the gross price markup over marginal cost. Without costs of price adjustment ($\phi_P = 0$), this markup is constant and equal to $\theta_f/(\theta_f - 1)$. With this formulation it is straightforward to see that all supply side shocks affect the magnitude and the cyclical properties of the markup.

[3] Alternative ways to include nominal rigidities include the Calvo (1983) or Taylor (1980) models of staggered prices. As these schemes have similar implications for the dynamics of aggregate inflation, the choice is not crucial for our purposes.

2.3 The government sector

The government determines the level of taxes and bond supply, while the central bank determines the level of the money market interest rate.

The government budget constraint is given by

$$\frac{B_t}{P_t} + \frac{B_{M,t}}{P_t} + \frac{B_{L,t}}{P_t} + \frac{M_t}{P_t} + \tau_t$$
$$= R_{t-1}\frac{B_{t-1}}{P_t} + R_{M,t-1}\frac{B_{M,t-1}}{P_t} + R_{L,t-1}\frac{B_{L,t-1}}{P_t} + \frac{M_{t-1}}{P_t} + g_t, \quad (33)$$

where g_t is government spending. For simplicity, define the government's total liabilities as

$$h_t := R_t\frac{B_t}{P_t} + R_{M,t}\frac{B_{M,t}}{P_t} + R_{L,t}\frac{B_{L,t}}{P_t} + \frac{M_t}{P_t}. \quad (34)$$

Then I can rewrite the government budget constraint as

$$h_t + (R_t - R_{M,t})\, b_{M,t} + (R_t - R_{L,t})\, b_{L,t} = \frac{R_t}{\pi_t} h_{t-1} + R_t\,(g_t - \tau_t) - (R_t - 1)m_t \quad (35)$$

In order to close the model, I assume that the real supply of medium and long-term bonds follow the exogenous processes

$$\ln(b_{\iota,t}/b_\iota) \quad = \quad \rho_\iota \ln\left(b_{\iota,t-1}/b_{\iota)}\right) + \nu_t^\iota, \quad (36)$$

for $\iota = M, L$, where ν_t^ι are i.i.d. shocks with zero mean and constant σ_ι^2. The exogenous supply of bonds plays a role also in Piazzesi and Schneider (2007), who study the impact on portfolio allocation in a partial equilibrium model.[4]

To avoid the emergence of inflation as a fiscal phenomenon, as in Leeper (1991) and Schmitt-Grohé and Uribe (2006), I assume a feedback rule for fiscal policy such that the total amount of tax collection is a function of the total government's liabilities outstanding in the economy:

$$T_t = \psi_0 + \psi_1\,(h_{t-1} - h)\,, \quad (37)$$

where T_t is nominal lump-sum taxes. I assume that government expenditure follows the exogenous AR(1) process

$$\ln(g_t/g) = \rho_g \ln(g_{t-1}/g) + \nu_t^g, \quad (38)$$

where ν_t^g is a disturbance term with zero mean and variance σ_g^2.

[4]For empirical evidence on the effects of bond supply shock on the term structure of U.S. Treasury bills, the reader can refer to Jovanovic and Rousseau (2001) and Krishnamurthy and Vissing-Jorgensen (2008).

2.4 Monetary policy

The central bank is assumed to set the money market interest rate R_t according to the Taylor (1993) rule

$$\ln\left(\frac{R_t}{R}\right) = \alpha_R \ln\left(\frac{R_{t-1}}{R}\right) + (1-\alpha_R)\left\{\ln\left(\frac{\pi_t^*}{\pi}\right) + \alpha_\pi\left[\ln\left(\frac{\pi_t}{\pi}\right) - \ln\left(\frac{\pi_t^*}{\pi}\right)\right]\right.$$
$$\left. + \alpha_y \ln\left(\frac{y_t}{y}\right) + \alpha_m \ln\left(\frac{m_t}{m_{t-1}}\pi_t\right)\right\} + \epsilon_t^R, \quad (39)$$

where hats denote log deviations from the deterministic steady state. The autoregressive shock ϵ_t^R captures non-systematic monetary policy. The policy rate is determined as a function of the deviations of inflation, output and nominal money from the respective targets with a gradual adjustment. The central bank targets the level of output y at the steady state. The policy rule features a time-varying inflation target π_t^* along the lines of Smets and Wouters (2003)

$$\ln\left(\frac{\pi_t^*}{\pi}\right) = \rho_\pi \ln\left(\frac{\pi_{t-1}^*}{\pi}\right) + \nu_t^\pi \quad (40)$$

around the long-run value of inflation π, with an autoregressive shock ϵ_t^π.

Following Andrés, López-Salido and Nelson (2004) and Andrés, López-Salido and Vallés (2006), I allow for an additional channel of propagation of money demand shocks through the central bank's reaction function. This can be thought of as mimicking the scope for the 'monetary pillar' of the ECB. From a technical point of view, Ireland (2004) suggests that including a monetary target helps identifying the slope of the IS curve.

2.5 Resource constraints

Finally, the model is completed by the resource constraints

$$y_t = c_t + i_t + g_t + \frac{\phi_P}{2}\left(\pi_t - \gamma_P\pi - (1-\gamma_P)\pi_{t-1}\right)^2 y_t$$
$$+ \frac{\phi_w}{2}\left(\frac{w_t}{w_{t-1}}\pi_t - \gamma_W\pi - (1-\gamma_W)\pi_{t-1}\right)^2 w_t$$
$$+ b_{M,t}\frac{\phi_S}{2}\left(\frac{b_{M,t}}{b_{M,t-1}}\right)^2 y_t + b_{L,t}\frac{\phi_L}{2}\left(\frac{b_{L,t}}{b_{L,t-1}}\right)^2 y_t$$
$$+ m_t\left[\frac{\upsilon_M}{2}\left(\frac{m_t}{b_{M,t}}\kappa_S - 1\right)^2 + \frac{\upsilon_L}{2}\left(\frac{m_t}{b_{L,t}}\kappa_L - 1\right)^2\right] y_t. \quad (41)$$

Thus, total output is allocated to consumption, investment (including the capital adjustment cost), government spending, the price adjustment cost, and the sum of adjustment costs for bond and money holdings.

2.6 Model summary

The complete model consists of 19 equations for the 19 endogenous variables: the household budget constraint (7), the capital accumulation equation (5), the households' optimality conditions (18)–(25), the production function (26), the firms' optimality conditions in (30)–(32), the government's total liabilities in (34), the government budget constraint (35), the fiscal policy rule (37), the monetary policy rule (39), and the resource constraint in (41). In addition, the model includes twelve exogenous processes: three types of shocks to preferences, an investment shock, a technology shock, a price shock, a wage markup shock, the two bond supply equations, a government spending shock, a monetary policy shock, and an inflation-target shock.

2.7 An overview of the feedback from the term structure

The model features imperfect substitution between assets through costs of changing the ratio between medium and long-term bonds and money holdings. This implies that the log-linearized demand for money depends on the money market rate and the quantities of bonds with medium and long maturities

$$\Lambda m^{-\chi}\hat{\epsilon}_t^m - \left[\Lambda\chi m^{-\chi} + (v_M + v_L)\lambda y\right]\hat{m}_t + \frac{\beta}{\pi}\lambda E_t\hat{\lambda}_{t+1} - \frac{\beta}{\pi}\lambda E_t\hat{\pi}_{t+1} = \lambda\hat{\lambda}_t - v_M\lambda y\hat{b}_{M,t} - v_L\lambda y\hat{b}_{L,t} \quad (42)$$

Holdings of short-term bonds adjust in a frictionless way, and are priced from expected changes in the marginal utility consumption

$$\hat{R}_t + E_t\hat{\lambda}_{t+1} - E_t\hat{\pi}_{t+1} = \hat{\lambda}_t. \quad (43)$$

The expectations hypothesis of the term structure does not hold in the model because of the presence of frictions in the bond market. The prices of medium and long-term bonds respond to variations in bond quantities and money

$$\begin{aligned}\beta\frac{R_\iota}{\pi}\lambda\hat{R}_{L,t} + \beta\lambda\left(\frac{R_\iota}{\pi} + \phi_\iota y\right)E_t\hat{\lambda}_{t+1} \\ - \beta\frac{R_\iota}{\pi}\lambda E_t\hat{\pi}_{t+1} + \beta\phi_\iota\lambda y E_t\hat{y}_{t+1} + 3\beta\phi_\iota\lambda y E_t\hat{b}_{L,t+1} = \\ \lambda\left(1 + \frac{3}{2}\phi_\iota y\right)\hat{\lambda}_t + \frac{3}{2}\lambda\phi_\iota y\hat{y}_t - 3\phi_\iota\lambda y\hat{b}_{L,t-1} \\ + \left[3\phi_\iota\lambda y(1+\beta) - \lambda v_\iota y\frac{m}{b_\iota}\right]\hat{b}_{L,t} + \lambda v_\iota\frac{m}{b_\iota}y\hat{m}_t \quad (44)\end{aligned}$$

for $\iota \in \{M, L\}$. Since the bond adjustment costs penalize changes in bond holdings across periods, both lagged and expected quantity variations affect the pricing.

The feedback from the term structure to the macroeconomy operates through two channels. The first channel arises from the imperfect substitution between bonds and money. The pricing equation 43 for the money market instrument can be used to rewrite the Euler equation 44 for medium and long-term bonds in terms of spreads from the short-term interest rate. The resulting expression provides a law of motion for the evolution of the money-bond ratios at medium and long-term, and can then be substituted into the equilibrium demand for money 42. The reduced-form demand for money is a function of all the yields from the term structure. Since the Taylor rule 39 responds directly to changes in money demand, long-term rates feed through to the policy rate. The second feedback channel from the term structure is related to the wealth value of bonds. The Euler equation for long-term bonds can be detracted from that of short-term bonds to solve for the shadow value of the household's budget constraint. This way, long-term interest rates affect consumption choices.

3 Estimation methodology

3.1 Data

The model is estimated on aggregate Euro-area data at a quarterly frequency for a period spanning from 1980:1 to 2007:2. I use twelve observable variables consisting of output, consumption, investment, wages, employment heads, inflation, a monetary aggregate, a money market rate, a medium and a long-term interest rate.[5]

A proper series for hours worked is not available. Like Smets and Wouters (2003), I estimate the model using a measure of employment heads. I link the observable to hours by assuming that only a fraction ξ_e of firms can adjust the stock of employees $\hat{e}_t$ as a function of the desired labour input

$$\hat{e}_t = \beta \hat{e}_{t+1} + \frac{(1-\beta\xi_e)(1-\xi_e)}{\xi_e}\left(\hat{\ell}_t - \hat{e}_t\right), \tag{45}$$

where all the variables are expressed as log-deviations from the steady state.

Yield curve data include average interest rates on bonds of maturities at 3 months, 2 and 10 years. The series for money demand consists of an indicator for M3. From the second half of 2001 until the end of 2003, M3 has grown strongly in the Euro area. This development has been caused by sizeable portfolio shifts from equity to money (see ECB, 2003, 2004). As argued in ECB (2004), these shifts may reflect a flight to safety and, as such, enhanced liquidity preferences by investors. In this paper, I use the unadjusted indicator for M3.[6] Finally, the inflation rate is obtained from the first difference of the harmonized index of

[5] The data have been downloaded from the Statistical Data Warehouse of the ECB.

[6] A number of series for M3 adjusted for the estimated impact of extraordinary portfolio shifts and technical factors was kindly made available by Björn Fischer. However, I choose not to use the adjusted series M3 for that would wipe away the money demand shocks due to the flight to safety. However, it remains to be investigated whether these shocks can reflect a structural break in the existing money demand relationship.

consumer prices (HICP) at a quarterly frequency.

The original data series for the yields and M3 are available at a monthly frequency. They are aggregated as quarterly averages. Prior to estimation, all the series are deflated by the level of the HICP. The dataset is then detrended using a linear trend. For the interest rates, I use the trend of the inflation rate.

3.2 Estimated parameters

The optimality conditions of the model are loglinearized to obtain a system of linear rational expectations equations.[7] The system is solved through standard methods,[8] and the solution is cast in state-space form. Then the likelihood function $f(Y^T|\Theta)$ is evaluated using a Kalman, where Θ denotes the parameter vector and Y^T is the sample of observable variables. Given a set of priors $g(\Theta)$, the posterior distribution

$$g(\Theta|Y^T) \propto f(Y^T|\Theta)g(\Theta) \tag{46}$$

is maximized with respect to Θ through Markov Chain Monte Carlo methods. The parameter space consists of 40 parameters, out of which 16 determine the non-stochastic part of the model

$$\Theta_1 := [\ \sigma,\ \gamma,\ \chi,\ \psi,\ \phi_K,\ \phi_P,\ \gamma_P,\ \phi_W,\ \gamma_W,\ \xi_e,\ \upsilon_M,\ \upsilon_L,\ \alpha_R,\ \alpha_\pi,\ \alpha_y,\ \alpha_m\ ], \tag{47}$$

and 24 are related to the exogenous shocks

$$\Theta_2 := [\ \rho_p,\ \rho_m,\ \rho_\ell,\ \rho_i,\ \rho_a,\ \rho_P,\ \rho_w,\ \rho_g,\ \rho_M,\ \rho_L,\ \rho_R,\ \rho_\pi\ ], \tag{48}$$

$$\Theta_3 := [\ \sigma_p,\ \sigma_m,\ \sigma_\ell,\ \sigma_i,\ \sigma_a,\ \sigma_P,\ \sigma_w,\ \sigma_g,\ \sigma_S,\ \sigma_L,\ \sigma_R,\ \sigma_\pi\ ]. \tag{49}$$

3.3 Calibrated parameters

A number of parameters are fixed due to the fact that the dataset is uninformative for their estimation. Their values are reported in Table 2. These parameters are calibrated to match the long-run values of the observables, as reported in Table 1, and consistently with the steady state relations of the model.

The discount factor β is calibrated from the long-run relation between inflation and the short-term rate. The depreciation rate δ is 2.5% per quarter. Given a labor-income share in total output of 70%, I set α to 0.3. From an investment-output ratio equal to 0.2, I calibrate

[7] Appendix A presents the full system.

[8] In particular, I use the gensys algorithm of Chris A. Sims.

the fixed cost of production. The steady-state markups for prices and wages are calibration to 1.2 and 1.05 respectively, following Christiano, Motto and Rostagno (2007).

The bond-adjustment costs are not estimated because they are pinned down from the steady-state spreads between the yields. Hence, for each bond, the adjustment cost is chosen to match average yields reported in Table 1. This gives $\phi_M = 0.0006$ and $\phi_L = 0.007$.

The debt to GDP ratio in steady state is set to 45 percent. The fractions of medium and long-term debt are computed from monthly series of gross issues against cash available from the ECB's Statistical Data Warehouse. The ratio of public spending to GDP in steady state is 19.86 percent, while the tax to GDP ratio is 19.1 percent.

The feedback parameter ψ_1 on the fiscal policy rule is of special interest because it largely affects the determinacy properties of the model. I fix it to 0.92 which, within the range of reasonable values, should yield fiscal policy as 'passive' in the sense of Leeper (1991). This way, lump-sum taxes are not allowed to act independently from the outstanding stock of government's liabilities, and are set to avoid an explosive path for public debt.

3.4 Prior distributions

The priors distributions are reported in the first half of Table 3. The assumptions on the prior distributions are largely similar to those of Smets and Wouters (2003). All the variances of the shocks follow an inverted Gamma distribution with two degrees of freedom, so that the estimates fall in the region of positive values. The autoregressive parameters of the shocks have a Beta prior distribution with a small standard error. Most of the preference and technology parameters follow either a Normal or a Beta distribution with means consistent with previous studies. The intertemporal elasticity of substitution has a prior mean equal to one, consistently with the log utility in consumption that is typically used in estimated models (e.g. see Christiano, Motto and Rostagno, 2007). The prior mean for the money demand elasticity that is higher than what Andrés, López-Salido and Vallés (2006) estimate on Euro area data. However, it is consistent with the estimates for the U.S. economy of Andrés, López-Salido and Nelson (2004). For the parameters on the adjustment cost functions for investment, prices and wages, I assumed a diffuse prior with starting values. These prior means are broadly in line with the available estimated models the U.S. economy (see Laforte, 2003 and Kim 2000), but lower than the values used in calibrated models of the Euro area (e.g. see Bayoumi, Laxton and Pesenti, 2004). After some preliminary estimation trials, I choose rather diffuse priors on the adjustment cost parameters between bonds and money. The model theory of imperfect substitutability between money and bonds suggests that the longer the maturity of a bond, the more households should be willing to 'liquidate' the bond. Hence the prior means should be such that $v_M > v_L$. It should be stressed, however that this restriction is not imposed during the posterior maximization. Finally, there are rather standard priors on the parameters of the Taylor rule. However, since the shape of the parameter regions that generate unique equilibria are unknown due to the new features of the model, the prior mean on the inflation coefficient is larger than usual, and the prior distribution has a higher standard deviation.

4 Estimation results

4.1 Parameter estimates

Table 3 reports the statistics for the posterior distribution, including the mode, the standard errors of the posterior estimates from the inverse of the Hessian, and the 5 and 95 percentiles. Figure 2 plots the shapes of the prior distributions, together with a Kernel approximation of the posterior distributions. The posteriors are obtained through the Metropolis-Hastings algorithm with 1500000 draws. The estimation does not include measurement errors. A number of estimation trials shows that estimation errors are statistically non-significant.[9]

All the parameters are estimated rather precisely. The estimates of the intertemporal elasticity of substitution are closer to the lower range of values used in the business cycle literature (e.g. see Rotemberg ad Woodford, 1992). Households have a degree of habit formation at the mode lower than what is obtained by Smets and Wouters (2003). The labour supply elasticity is estimated consistently larger than one. The elasticity of money demand is about twice as large as the estimates of Andrés, López-Salido and Vallés (2006). The model of Andrés, López-Salido and Vallés (2006) differs with the one estimated in this paper in many ways. Their framework does not include wage frictions, and has only a small number of shocks. Finally, Andrés, López-Salido and Vallés (2006) use quarterly Euro area data for a different time span ranging from 1980:1 to 1999:4. The parameters on the adjustment costs between bonds and money follow the relation that one would expect from the theory. They are of the order of magnitude of the calibration proposed by Marzo, Söderström and Zagaglia (2008) for the U.S. The estimates of the coefficients in the Taylor rule deliver a high degree of policy inertia, a strong reaction to inflation, and a positive response to output, which is broadly in line with the estimates of Smets and Wouters (2003). The interest rate reaction to money demand features a positive coefficient that is statistically different from zero.

The estimates of the adjustment cost parameters of prices and wages are much higher than those of the available literature (e.g. see Kim, 2000 and Amisano and Tristani, 2007). The parameter of the investment adjustment costs can be reconciled with those of Christiano, Eichenbaum, and Evans (2005). Most of the autoregressive shocks have a degree of persistence lower than the prior mean, with the exceptions of the labour supply and investment shocks. Finally, the posterior modes of the standard deviations of the shocks are on average larger than those obtained by Christiano, Motto and Rostagno (2007). This can be attributed to

[9] The validity of the results from Bayesian estimation rests on the convergence of the Markov chain. I tackle this issue by chekcing the plots of the running means of the marginal posteriors as suggested by Bauwens et al. (1999). I also apply the separated partial means tests of Geweke (2005, p. 149). The results suggests that there is strong convergence for all the estimated parameters.

the fact that their estimation uses measurement errors, which enhances the flexibility of the model in fitting the data series.

4.1.1 The stability of estimates: what frictions are important?

In order to check the stability of the estimates, I run an extensive sensitivity analysis by. Table 4 reports the estimated posterior modes of models where nominal or real frictions are shut down. For instance, I re-estimate the model under the restriction of no nominal price stickiness by fixing $\phi_P = 0.001$, and by using the benchmark prior assumptions for other parameters from Table 3. I consider also models with no wage rigidity $\phi_W = 0.001$, no investment-adjustment costs $\phi_K = 0.001$, no adjustment costs between bonds and money $v_M = v_L = 0$, and no consumption habits ($h = 0$). Table 4 shows that there are no major changes to the benchmark posterior modes. The last line of Table 4 indicates that removing real or nominal rigidities worsens the empirical fit as the log marginal likelihood of the models declines with respect to the benchmark.[10] The model without adjustment costs between bonds and money generates the largest drop in marginal likelihood. This confirms the empirical validity of the restrictions considered in this model in the relation between bonds and money. In Table 5, I report the posterior modes when a number of demand and supply shocks are have no variation. Shocks to bond supply, money demand and wage markups are the most important in terms of induced decline in marginal likelihood.[11]

4.2 Model fit

In this section, I investigate the ability of the model to capture the main features of the data. A standard metric considers how close the pattern of empirical covariances is to those generated by the DSGE model. For this purpose, I compute cross-covariances from a VAR(1) model estimated on the full sample of the ten observable variables. These empirical covariances are then compared with those from a VAR(1) estimated on simulated data from the DSGE model. In the simulations, I generate 10000 draws of 150 observations for each variable. For each draw, the cross-covariances are computed, and the median, and the median and the median is derived along with the 10% and 90%. Figures 3-4 report the results for a number of variables. Circles indicate the empirical correlations, whereas bold lines are model correlations. The plots depict also 10% and 90% confidence bands. The bands tend are tight on average, with most of the empirical covariances falling inside them. The DSGE model matches the empirical patterns fairly well, especially the dynamic relations between the term structure and the other macro variables.

[10]The log marginal likelihood is computed through the modified harmonic mean like in Smets and Wouters (2004).

[11]I also experiment with different shapes for the priors of the parameters that affect the term structure.The estimated modes of the posterior distributions are again rather close to the benchmark estimation results. The marginal likelihood displays only minor changes. Overall, the estimates are robust to a changes of different types to the prior assumptions.

Additional dimensions for evaluating the model include the fit in-sample and out-of-sample. Table 6 reports the root mean squared errors (RMSE) from in-sample forecasting. The DSGE model is compared with other VAR models with different lag lengths estimated on the dataset of observables. The VAR(1) has the best predictive performance for most of the series. However, the increase the other models do not generate any major increase in RMSE. Also, the DSGE model does worse only to a marginal extent.

Posterior predictive checks provide a synthetic indication of the predictive ability out-of-sample. To give a detailed picture, I report the root mean squared errors for forecasts up to one year ahead in Figure 5. These statistics are computed by estimating the models until 2002:4. The forecast evaluation starts in 2003:1. The models are then re-estimated quarter after quarter while generating the forecasts. The competing models include the VAR(1), the BVAR(3), and a random walk. With respect to macro variables, the DSGE model of the term structure generates the best predictions for inflation and output over all the horizons. Its performance is close to the one of the best model for both consumption and the monetary aggregate. The model does not perform as well for investment, employment and wages. The predictive power of the DSGE model for the bond yields is close to best at the longer horizons, as the VAR models tend to do better for up to 4 quarters ahead. This is in stark contrast with the results of De Graeve, Emiris and Wouters (2009). They use the model of Smets and Wouters (2003) to generate bond yields that are consistent with the expectations hypothesis. As they estimate the system using Bayesian methods, they model yield premia as measurement errors. De Graeve, Emiris and Wouters (2009) find that their DSGE model never outperforms the benchmark forecasts for a ten-year yield. Moreover, their DSGE model produces superior forecasts for short maturities at longer horizons.

5 Financial market frictions and the term structure

5.1 What moves bond yields?

Table 7 shows the contribution of the shocks to the forecast error variance of the observable variables at 1 quarter, 1 and 10 years ahead. The model presented in this paper captures patterns of shock contribution for the real variables rather similar to those depicted in Smets and Wouters (2003). At the same time, money demand shocks take up a role that has not been detected in the literature.

Changes in output are driven primarily by shocks to preferences, monetary policy, and technology. Money demand shocks do not contribute to fluctuations in output in the long run. However, consistently with the findings of Andrés, López-Salido and Vallés (2006), they they explain 7% of the variation of consumption. Since quantities of bonds at medium and long-term enter the resource constraint, shocks to bond supply account for 10% of the variance of output.

Similarly to the results of Kim (2000) for the U.S. and Andrés, López-Salido and Vallés

(2006) for the Euro area, money demand shocks account for 10% of the long-run variance of inflation. Real money balances are driven by shocks to the monetary policy rule, and to money demand. Bond supply shocks matter because of the relation of imperfect substitutability between bonds and money.

The last three columns of Table 7 report the decomposition for the bond yields. Similarly to the results De Graeve, Emiris and Wouters (2009) for the U.S. and Smets and Wouters (2004) for the Euro area, the shock to the inflation target is the main driver of the dynamics of the term structure at long horizons, together with the shocks to money demand and bond supply. The contribution of the monetary policy shock declines along the maturity structure. The money demand shock, and the shocks to the supply of bonds accounts for more than one third the volatility of long-term rates.

In order to shed light on the dynamics of the yields, Figures 6-8 plot the impulse responses (in percentage points) to shocks to money demand, and to the supply of medium and long-term bonds respectively. Figures 9(a)-10(d) show the impulse responses of the term structure to the other shocks. The responses for each shock are computed for a draw of 10000 parameters from the posterior sample. The figures report the median response together with the 10 and 90 percentile.

An exogenous increase in money demand generates a large and persistent increase in the money market rate. This causes households to cut back on consumption and investment, leading to a slump in output (see Figure 6). Inflation drops below steady state because of the increase in the policy rate. However, the fall in inflation is smaller than the increase in money demand. The hike in the policy rate takes counteracts the exogenous increase in money demand. This is consistent with the results of Kim (2000), who introduces a money supply rule that does not fully accomodate the shock. The positive reaction of the policy rate causes the term structure to move upward.

One of the advantages of the modelling strategy for yields presented in this paper is that it allows to obtain impulse responses for model-consistent term premia, which are also plotted in Figure 9(a). Like in the empirical literature on the term structure (e.g. see Mumtaz and Surico, 2008), the premium ξ_t can be computed as

$$R_{L,t} = \frac{1}{120}\sum_{j=0}^{119} \mathsf{E}_t R_{t+j} + \xi_t, \tag{50}$$

where 120 is the number of periods to maturity, and R_t is the short-term interest rate. Thus, the term premium is the deviation of the long-term yield $R_{L,t}$ from the level consistent with the expectations hypothesis, $(1/n)\sum_{j=0}^{n-1} \mathsf{E}_t R_{t+j}$. This measure of premia depends on the adjustment costs of bonds that drive the long-term yield away from the level consistent with the expectations hypothesis.[12] The extent to which households reallocate resources between

[12]The available literature typically prices bonds at long maturities through higher order Taylor approximations of the recursive stochastic discount factor (e.g. see Ravenna and Seppälä, 2008 and Rudebusch

bonds and money can be viewed as a proxy for the attitude towards risk. Figure 6 shows that this measure of term premia track the shape of the response of the long-term rates. Their size is about one tenth of the movement of the long rate.

Figure 7 shows that an exogenous increase to the supply of medium-term bonds rises the medium-term yield. In order to close the wedge induced by the transaction costs between bonds and money, real money holdings persistently. This is also supported by a drop in inflation over a long horizon. For the money market to clear, both the short and the long-term rate fall. In the period when the shock occurs, the rise in the policy rate is entirely motivated by the need to counteract money demand changes. In the subsequent periods, the policy rate falls the path of inflation. As a result, the term spread becomes negative in the first period, and then rises above zero. Output and consumption increase on impact, and then fall below steady state. A positive shock to the supply of long-term bonds generate the same pattern for the dynamics of output, inflation and the policy rate (see Figure 8). However, in this case, long-term yields rise, and the term spread falls.

An exogenous increase in the short term rate generates a persistent drop in output and inflation (see Figure 9(a)). The fall in inflation increases the real value of outstanding debt. However, the reduction in output and consumption requires the yields to rise. This is consistent with a decline in the price of bonds for the financial markets to clear. The fall in the demand of bonds and the initial increase in the opportunity cost of money causes money demand to fall below steady state. The response of the yields is decreasing along the term structure. This is a pattern largely documented in the VAR literature (e.g. see Evans and Marshall, 1998). A shock of one percent standard deviation at the mode moves the long term rate by approximately one third of the increase in the policy rate. This is broadly consistent with the results of Peersman and Smets (2003) from identified VARs. Consistently with the qualitative findings of Rudebusch, Sack, and Swanson (2007), a monetary policy shock leads to an increase in term premia. The magnitude of the response at the peak is about one tenth the response of the long-term rate.

Finally, Figure 9(b) reports the impulse responses to a positive shock to the inflation target. On impact there is a hike in the policy rate because inflation expectations increase. Given the inertial reaction of monetary policy, the gradual adjustment of inflation expectations prevents output from over-reacting. The long-term yields follow the increase in the money market rate. This generates a hike in term premia of approximately one fourth the rise in the long-term rate.

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and Swanson, 2008). This way, the cross-products between the endogenous variables and the variances of the exogenous shocks generate bond prices that are affected by time variation in risk. The term premia computed from these bond yields are functions of the sources of market risk in the model. As suggested earlier, the premia depicted in Figure 9(a) are driven by other factors, in particular by the relation of imperfect substitutability between bonds and money.

5.2 What macroeconomic role for the term structure?

Since the key challenge of the macro-finance literature consists in modelling bond yields and macroeconomic variables jointly (see Rudebusch, Sack, and Swanson, 2007), it is important to understand what additional information about the monetary transmission mechanism arises from introducing the yields in the DSGE. This also raises the question of how the financial market frictions embedded in the model affect the interpretation of the monetary transmission.

Given these issues, I estimate a version of the DSGE without medium and long-term rates. In other words, I remove the bond adjustment costs and the adjustment costs between bonds and money. The resulting DSGE is a prototype New Keynesian model with money in the utility function, price and wage rigidity arising from quadratic adjustment costs. Bond supply shocks drop out of the model. The resulting 'restricted' DSGE is then estimated on the dataset described earlier with the exclusion of bond yields at medium and long maturities, for a total of eight series. The 32 parameters are assigned the same priors used for the 'benchmark' model with the term structure.

Table 8 reports the posterior modes of the restricted model. Without medium and long-term yields, the estimation delivers higher intertemporal elasticity of substitution and elasticity of money demand. This suggests that, by simplifying the portfolio allocation problem and removing frictions, households can use resources in a more flexible way. At the same time, there is a higher degree of habit formation. The estimated labour supply elasticity becomes lower because wages are slightly more flexible, though they become more indexed to the inflation target. From the perspective of the central bank, the estimated response to inflation falls. This happens because price setters face lower adjustment costs when changing nominal prices.

Without medium and long-term yields, the estimation delivers higher intertemporal elasticity of substitution and elasticity of money demand. This suggests that, by simplifying the portfolio allocation problem and removing frictions, households can use resources in a more flexible way. At the same time, there is a higher degree of habit formation. Additional light on the role of the shocks in the transmission mechanism is provided by Table 9, which reports the forecast error variance decomposition for the DSGE without term structure. A comparison with Table 7 reveals two things. The first one is that shocks to preferences, labour supply and technology are the most relevant in a model without the term structure. This is consistent with the results of Smets and Wouters (2004). The second point of relevance is that shocks to money demand and to non-systematic monetary policy are not important any longer in a model without the term structure. Removing the term structure implies that money demand shocks exert no indirect impact on the macroeconomy through bond yields.

In terms of model fit, the models with and without the term structure cannot be compared through likelihoold criteria because two different datasets are used for estimation. However, standard metrics for in-sample and out-of-sample forecasting can be applied. The last column of Table 6 reports the in-sample RMSEs for the model without the term structure. Removing the financial-market frictions from the model improves the prediction for consumption, investment, employment and wages. On the other hand, the in-sample forecasts for output, inflation, M3 and the policy rate are superior in the model with the term structure. The out-of-sample forecasts in Figure 5 show that the model with the term structure predicts both output ad inflation better than the standard New Keynesian model. This result is of interest especially because the model without the term structure is not a 'bad' forecasting model as it delivers a good predictive performance with respect to the random walk and the BVAR. Overall, these findings suggest that the modelling strategy for the term structure pursued in this paper generates information for predicting output and inflation that is not contained in the standard model without the term structure.

5.3 What determines the correlation between the yield spread and output?

Starting from Estrella and Hardouvelis (1991), a large body of literature has documented the predictive content of the spread between long and short-term bond yields for future output growth. As suggested by Benati and Goodhart (2008), this relationship can be retrieved in the U.S. and in the Euro area data. Traditional explanations for the predictive power of the yield spread emphasize the fact that asset prices incorporate market views on the current and future stance of monetary policy. As monetary policy tightens, the yield curve flattens and future output falls in the presence of nominal rigidity. In this section, I provide a structural interpretation on the role of the yield spread through the lenses of the DSGE model using a simple measure of predictive content.

The top panel of Table 10 reports the historical and model-implied correlations of the spread between the short and long-term rate and future output growth at various horizons. The historical correlations are computed over the full sample of the dataset discussed in Section 3. The model generates correlations rather close to the historical ones as it overshoots only by a small extent. However, it does not match the increase in correlation as a function of maturity.

The second panel Table 10 reports the model correlations (in level) when only one shock at the time is active. For a short horizon, investment shocks play the most important role. Figure 9(e) shows the impulse responses to this shock. An increase in the installment cost of investment generates a slump in output and a rise in firms' marginal costs. Bond yields respond positively to the shock, thus generating a fall in the spread along with output. The positive sign of the contribution to the correlation reflects the fact that a fall in the spread corresponds with negative growth rates at short horizons. The sign of the contribution changes when output starts rising. Shocks to money demand and to the wage markup are the second driver of the correlation. Monetary policy shocks also play a relevant role at short horizons. An exogenous rise in the policy rate induces a flattening of the yield curve (see Figure 9(a)). Output falls on impact and gradually recovers.

Government spending shocks generate a negative contribution because they take the form of an inflationary waste of resources in the model discussed here (see also Marzo, Söderström and Zagaglia, 2008). An exogenous increase in government spending leads to a rise in both output and inflation. As Figure 10(d) shows, the yield curve flattens, and the term spread becomes negative when output grows over time.

Shocks to the supply of medium-term and long-term bonds contribute to the movements of the spread with opposite sign. A supply shock to medium-term bonds generates a negative contribution because the positive response of output causes inflation and the money market rate to rise on impact. Following a shock to the supply of long-term bonds, long-term yields rise above the money market rate, which causes the term structure to steepen.

6 Conclusion

A large number of studies investigates the role of monetary policy and, in particular, changes in the central bank's inflation target for the dynamics of government bond yields. With few exceptions, the empirical literature ignores the policymakers' common view that the yield curve is a key part of the monetary transmission mechanism. In this paper, I estimate a DSGE model where bond yields affect both real and nominal variables. The theoretical framework is based on the 'theory of preferred habitat' of investors (see Vayanos and Vila, 2007 and Guibaud, Nosbusch and Vayanos, 2008) whereby portfolio allocation problems are characterized by sluggish decision as agents position themselves on desired market segments. The model incorporates also the suggestion by Tobin (1969) that liquidity preferences are proxies for the agents' attitude towards risk.

Estimating the model on quarterly Euro area data delivers two main results. First, I show movements in the term structure are driven by shocks to money demand and bond supply, besides shocks to monetary policy. Second, I evaluate the empirical reliability of the model and find that it delivers superior forecasts for output, inflation and bond yields with respect to both purely empirical models (such as VARs and BVARs) and to a standard New Keynesian model without the term structure.

The findings of this paper pave the way for relevant avenues of future research. It is clear that the model would benefit in terms of fit from the introduction of a money supply rule along the lines of Kim (2000). This would also allow to study the effects of the interaction between shocks to money demand and supply. This would shed light on the relation, if any at all, between expansionary liquidity policy and bond yields at the macro level. An interesting extension, which is currently being pursued, concerns the study of risk premia through a higher-order Taylor approximation of the first-order conditions. In particular, it would be important to understand if the feedback from the term structure can help solving the so-called 'bond premium puzzle' of Rudebusch and Swanson (2008), namely the finding that it is hard for a standard New Keynesian model to generate a realistic variation in risk premia while matching the cross-moments of output and inflation. Finally, the model estimated in this paper is currently being extended to include a banking sector where the mismatch between assets and liabilities of banks' balance sheets is related to the slope of the term structure. This issue appears of particular relevance in the context of the ongoing repricing of risk that is taking place in financial markets.

A Loglinearization

A.1 The system

A.1.1 Households

$$[(1-\gamma)c]^{1/\sigma}\,\lambda\hat{\lambda}_t = \frac{\beta}{\sigma}\frac{\gamma}{1-\gamma}E_t\hat{c}_{t+1} + \frac{1}{\sigma}\frac{\gamma}{1-\gamma}\hat{c}_{t-1} - \frac{1}{\sigma}\frac{1+\beta\gamma^2}{1-\gamma}\hat{c}_t + \hat{\epsilon}_t^p \tag{A1}$$

$$\begin{aligned}
&\Psi\frac{\theta_\ell}{w}\ell^{1/\psi}\hat{\epsilon}_t + \left(\Psi\frac{\theta_\ell}{w}\ell^{1/\psi} - \lambda\theta_\ell\ell\right)\hat{\theta}_{\ell,t} + \left[(1+1/\psi)\,\frac{\theta_\ell}{w}\ell^{1/\psi} + \lambda(1-\theta_\ell)\ell\right]\hat{\ell}_t \\
&-\left[\psi\frac{\theta_\ell}{w}\ell^{1/\psi} + \lambda\phi_w\pi^2(1+\gamma_w) - \lambda\phi_w\gamma_w\pi^*\pi - \beta\lambda\phi_w(1+2\gamma_w) - 2\beta\lambda\phi_w\pi^*\pi\right]\hat{w}_t \\
&-\lambda\left[\phi_w\gamma_w\pi(\pi-\pi^*) - (1-\theta_\ell)\ell\right]\hat{\lambda}_t \\
&+\lambda\phi_w\gamma_w\pi^*\pi\hat{\pi}_t^* - \left[\lambda\phi_w\left(\pi^*(1+\gamma_w) - \gamma_w\pi^*\pi\right) - \beta\lambda\phi_w(1-\gamma_w)\pi^2\right]\hat{\pi}_t \\
&+\beta\phi_w\lambda\phi_w\pi^*\pi\hat{\pi}_{t+1}^* + \lambda\phi_w\left(\pi^2(1+\gamma_w) - \gamma_w\pi^*\pi\right)\hat{w}_{t-1} + \lambda\phi_w(1-\gamma_w)\pi^2\hat{\pi}_{t-1} \\
&+\beta\phi_w\lambda\gamma_w\left(\pi-\pi^*\right)\hat{\lambda}_{t-1} + \beta\lambda\phi_w\gamma_w\pi\left(\pi-\pi^*\right)E_t\hat{\lambda}_{t+1} \\
&\quad+\beta\lambda\phi_w\left[(1+2\gamma_w)\pi^2 - 2\gamma_w\pi^*\pi\right]E_t\hat{w}_{t+1} + \beta\lambda\phi_w\left[(1+\gamma_w)\pi^2 - \gamma_w\pi^*\pi\right]E_t\hat{\pi}_{t+1}
\end{aligned} \tag{A2}$$

$$\begin{aligned}
&\Lambda m^{-\chi}\hat{\epsilon}_t^m - \left[\Lambda\chi m^{-\chi} + (v_M+v_L)\lambda y\right]\hat{m}_t + \frac{\beta}{\pi}\lambda E_t\hat{\lambda}_{t+1} - \frac{\beta}{\pi}\lambda E_t\hat{\pi}_{t+1} = \\
&\qquad\qquad \lambda\hat{\lambda}_t - v_M\lambda y\hat{b}_{M,t} - v_L\lambda y\hat{b}_{L,t}
\end{aligned} \tag{A3}$$

$$\hat{R}_t + E_t\hat{\lambda}_{t+1} - E_t\hat{\pi}_{t+1} = \hat{\lambda}_t \tag{A4}$$

$$\begin{aligned}
&\beta\frac{R_M}{\pi}\lambda\hat{R}_{M,t} + \beta\lambda\left(\frac{R_M}{\pi} + \phi_S y\right)E_t\hat{\lambda}_{t+1} - \beta\frac{R_M}{\pi}\lambda E_t\hat{\pi}_{t+1} \\
&\quad+\beta\phi_S\lambda yE_t\hat{y}_{t+1} + 3\beta\phi_S\lambda yE_t\hat{b}_{S,t+1} = \\
&\qquad\lambda\left(1+\frac{3}{2}\phi_S y\right)\hat{\lambda}_t + \frac{3}{2}\lambda\phi_S y\hat{y}_t - 3\phi_S\lambda y\hat{b}_{M,t-1} \\
&\qquad\qquad+\left[3\phi_S\lambda y(1+\beta) - \lambda v_M y\frac{m}{b_M}\right]\hat{b}_{M,t} + \lambda v_M\frac{m}{b_M}y\hat{m}_t
\end{aligned} \tag{A5}$$

$$
\begin{aligned}
&\beta\frac{R_L}{\pi}\lambda\hat{R}_{L,t}+\beta\lambda\left(\frac{R_L}{\pi}+\phi_L y\right)E_t\hat{\lambda}_{t+1}-\beta\frac{R_L}{\pi}\lambda E_t\hat{\pi}_{t+1}\\
&\quad+\beta\phi_L\lambda y E_t\hat{y}_{t+1}+3\beta\phi_L\lambda y E_t\hat{b}_{L,t+1}=\\
&\quad\lambda\left(1+\frac{3}{2}\phi_L y\right)\hat{\lambda}_t+\frac{3}{2}\lambda\phi_L y\hat{y}_t-3\phi_L\lambda y\hat{b}_{L,t-1}\\
&\qquad+\left[3\phi_L\lambda y(1+\beta)-\lambda v_L y\frac{m}{b_L}\right]\hat{b}_{L,t}+\lambda v_L\frac{m}{b_L}y\hat{m}_t
\end{aligned}
\tag{A6}
$$

$$
\beta(1-\delta)\mu E_t\hat{\mu}_{t+1}=\mu\hat{\mu}_t-\lambda q\hat{\lambda}_t-\lambda q\hat{q}_t \tag{A7}
$$

$$
\begin{aligned}
&\beta\mu\phi_K E_t\hat{\mu}_{t+1}+3\beta\mu\phi_K E_t\hat{i}_{t+1}=\lambda\hat{\lambda}_t+\mu\left(\frac{3}{2}\phi_K+1\right)\hat{\mu}_t\\
&\qquad+\mu\left(\frac{3}{2}\phi_K+1\right)\hat{\epsilon}^i_t+\mu\phi_K(3+\beta)\hat{i}_t-3\mu\phi_K\hat{i}_{t-1}
\end{aligned}
\tag{A8}
$$

$$
\hat{e}_t=\beta\hat{e}_{t+1}+\frac{(1-\beta\xi_e)(1-\xi_e)}{\xi_e}\left(\hat{\ell}_t-\hat{e}_t\right) \tag{A9}
$$

A.1.2 Firms

$$
\hat{y}_t=\frac{y+\Phi}{y}\left[\hat{\epsilon}^a_t+\alpha\hat{k}_t+(1-\alpha)\hat{\ell}_t\right] \tag{A10}
$$

$$
\begin{aligned}
&(\theta_f\mathrm{mc}-\theta_f)\,\hat{\theta}_{f,t}+\theta_f\mathrm{mc}\theta_f\hat{\mathrm{mc}}_t+\beta\phi_P\gamma_P\,(\pi-\pi^*)\,\pi E_t\hat{\lambda}_{t+1}\\
&-\beta\phi_P\gamma_P\,(\pi-\pi^*)\,\pi\hat{\lambda}_t+\beta\phi_P\gamma_P\,(\pi-\pi^*)\,\pi E_t\hat{y}_{t+1}-\beta\phi_P\gamma_P\,(\pi-\pi^*)\,\pi\hat{y}_t\\
&-\beta\phi_P\gamma_P\pi\pi^*E_t\hat{\pi}_{t+1}+\beta\phi_P\left[\pi^2(1+\gamma_P)-2\gamma_P\pi\pi^*\right]E_t\hat{\pi}_{t+1}\\
&\quad=\phi_P\left(\pi^2\,(1+\gamma_P)-\gamma_P\pi^*\pi+\beta(1-\gamma_P)\pi^2\right)\hat{\pi}_t+\phi_P\pi\pi^*\hat{\pi}^*_t-\phi_P(1-\gamma_P)\pi^2\hat{\pi}_{t-1}
\end{aligned}
\tag{A11}
$$

$$
\hat{w}_t=\hat{\mathrm{mc}}_t+\frac{y}{y+\Phi}\hat{y}_t-\hat{\ell}_t \tag{A12}
$$

$$
q\hat{q}_t=\alpha\left(\frac{y+\Phi}{k}\mathrm{mc}\right)\hat{\mathrm{mc}}_t+\alpha\left(\frac{y}{k}\mathrm{mc}\right)\hat{y}_t-\alpha\left(\frac{y+\Phi}{k}\mathrm{mc}\right)\hat{k}_t \tag{A13}
$$

$$
\hat{w}_t+\hat{\ell}_t=\hat{q}_t+\hat{k}_t \tag{A14}
$$

A.1.3 Government and central bank

$$h\hat{h}_t = Rb\hat{R}_t + Rb\hat{b}_t + R_M b_M \hat{R}_{M,t} + R_M b_M \hat{b}_{M,t} + R_L b_L \hat{R}_{L,t} + R_L b_L \hat{b}_{L,t} + m\hat{m}_t \tag{A15}$$

$$T\hat{T}_t = \psi_1 h\hat{h}_{t-1} \tag{A16}$$

$$\begin{aligned} & b\hat{b}_t + b_M\hat{b}_{M,t} + b_L\hat{b}_{L,t} + m\hat{m}_t = \\ & \frac{R}{\pi}b\hat{R}_{t-1} + \frac{R}{\pi}b\hat{b}_{t-1} - \frac{R}{\pi}b\hat{\pi}_t + \frac{R_M}{\pi}b_M\hat{R}_{M,t-1} + \frac{R_M}{\pi}b_M\hat{b}_{M,t-1} - \frac{R_M}{\pi}b_M\hat{\pi}_t \\ & \qquad + \frac{R_L}{\pi}b_L\hat{R}_{L,t-1} + \frac{R_L}{\pi}b_L\hat{b}_{L,t-1} - \frac{R_L}{\pi}b_L\hat{\pi}_t + \frac{m}{\pi}\hat{m}_{t-1} - \frac{m}{\pi}\hat{\pi}_t + g\hat{g}_t - \tau\hat{\tau}_t \end{aligned} \tag{A17}$$

A.1.4 Resource constraint

$$\begin{aligned} & \left(1 - b_M\frac{\phi_S}{2} - b_L\frac{\phi_L}{2}\right) y\hat{y}_t = c\hat{c}_t + i\hat{i}_t + g\hat{g}_t \\ & \qquad + (\phi_S y)b_M\hat{b}_{M,t-1} + (\phi_L y)b_L\hat{b}_{L,t-1} + \frac{3}{2}(\phi_S y)b_M\hat{b}_{M,t} + \frac{3}{2}(\phi_L y)b_L\hat{b}_{L,t} \end{aligned} \tag{A18}$$

$$k\hat{k}_{t+1} = \left[1 - \frac{\phi_K}{2}\right] i\hat{\epsilon}^i_t + \left[1 - \frac{3}{2}\phi_K\right] i\hat{i}_t + (1-\delta)k\hat{k}_t + \frac{\phi_K}{2} i\hat{i}_{t-1} \tag{A19}$$

A.1.5 Exogenous variables and shocks

$$\ln(\epsilon^p_t) = \rho_p \ln(\epsilon^p_{t-1}) + \nu^p_t \tag{A20}$$

$$\ln(\epsilon^m_t) = \rho_m \ln(\epsilon^m_{t-1}) + \nu^m_t \tag{A21}$$

$$\ln(\epsilon^\ell_t) = \rho_\ell \ln(\epsilon^\ell_{t-1}) + \nu^\ell_t \tag{A22}$$

$$\ln(\epsilon^i_t) = \rho_i \ln(\epsilon^i_{t-1}) + \nu^i_t \tag{A23}$$

$$\ln\left(\epsilon^a_t\right) = \rho_a \ln\left(\epsilon^a_{t-1}\right) + \nu^a_t \tag{A24}$$

$$\ln(\epsilon_t^w) = \rho_w \ln(\epsilon_{t-1}^w) + \nu_t^w \tag{A25}$$

$$\ln(\epsilon_t^P) = \rho_P \ln(\epsilon_{t-1}^P) + \nu_t^P \tag{A26}$$

$$\ln\left(b_{M,t}/b_M\right) = \rho_M \ln\left(b_{M,t-1}/b_M\right) + \nu_t^M \tag{A27}$$

$$\ln\left(b_{L,t}/b_L\right) = \rho_L \ln\left(b_{L,t-1}/b_L\right) + \nu_t^L \tag{A28}$$

$$\ln\left(g_t/g\right) = \rho_g \ln\left(g_{t-1}/g\right) + \nu_t^g \tag{A29}$$

$$\ln\left(\pi_t^*/\pi\right) = \rho_\pi \ln\left(\pi_{t-1}^*/\pi\right) + \nu_t^\pi \tag{A30}$$

$$\ln(\epsilon_t^R) = \rho_R \ln(\epsilon_{t-1}^R) + \nu_t^R \tag{A31}$$

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Figure 1: Data series

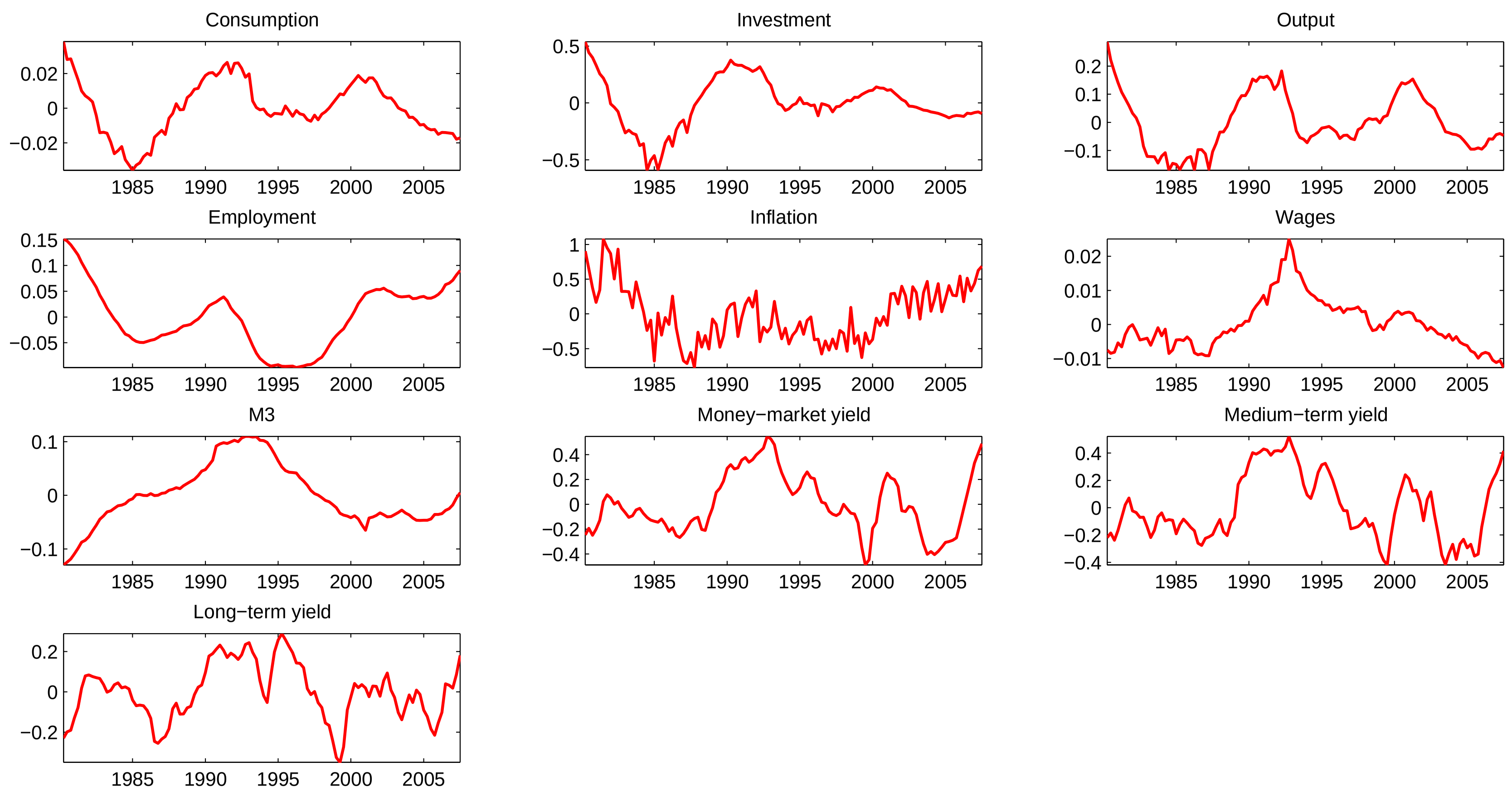
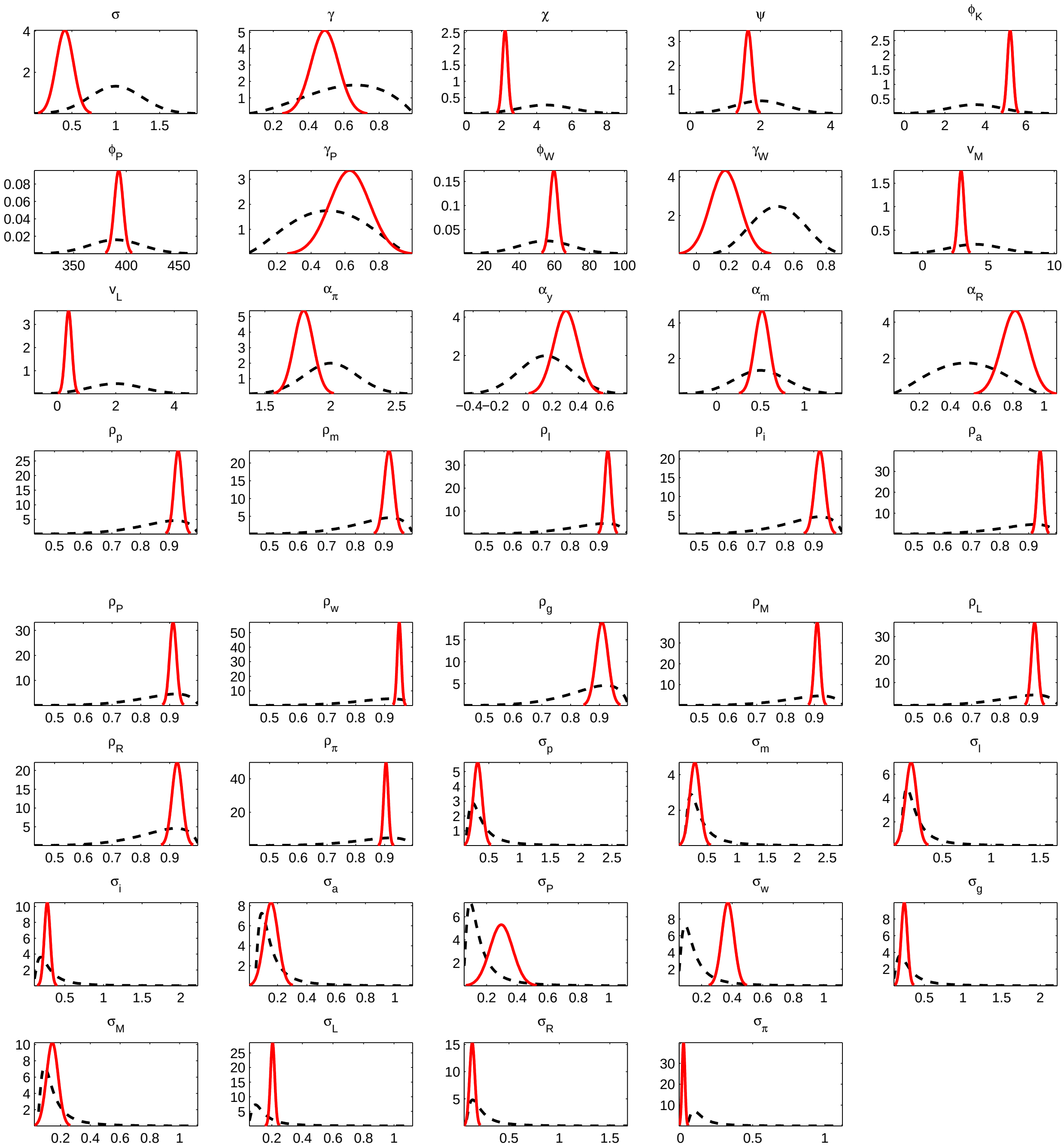
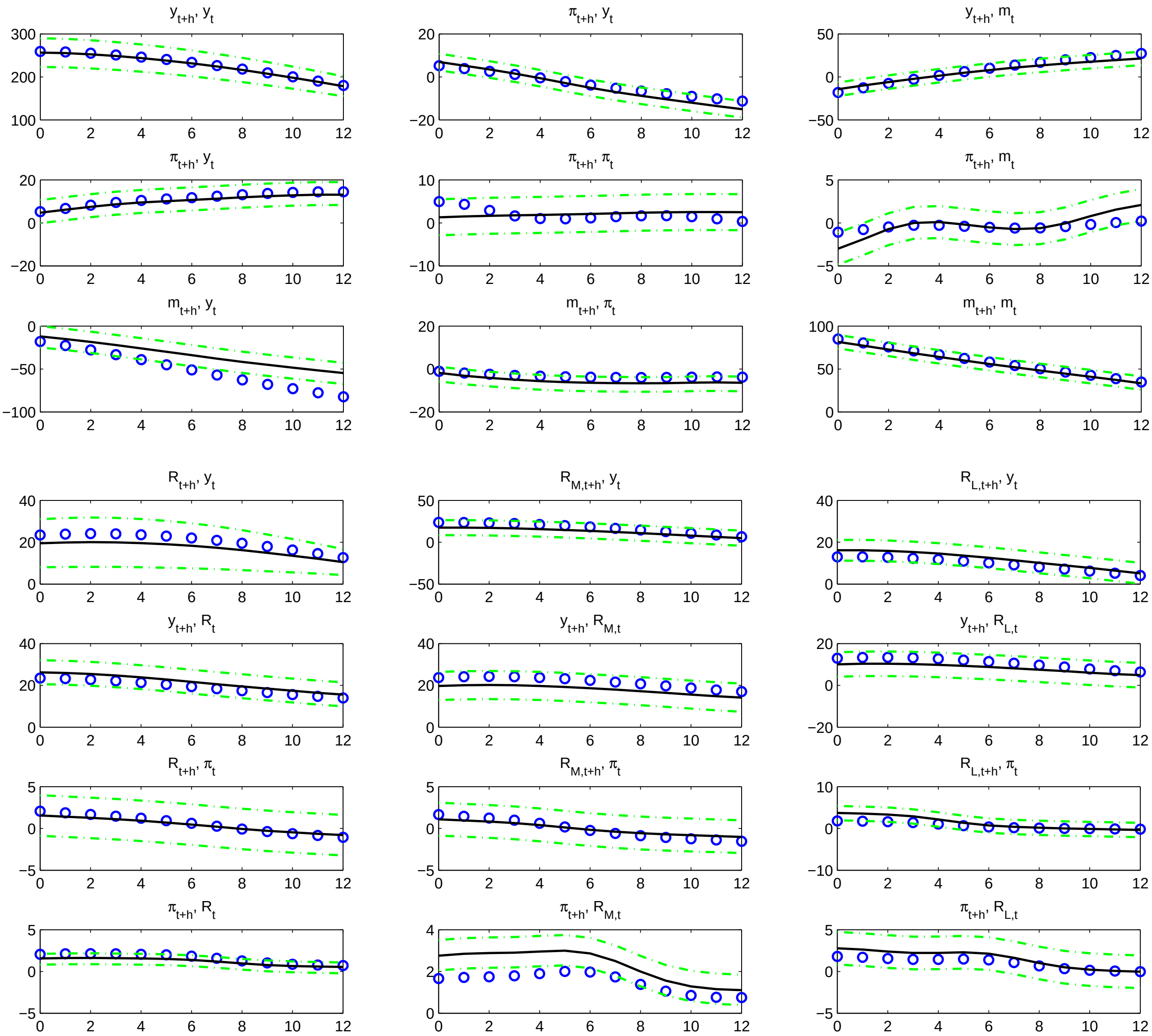


Figure 2: Prior and posterior distributions



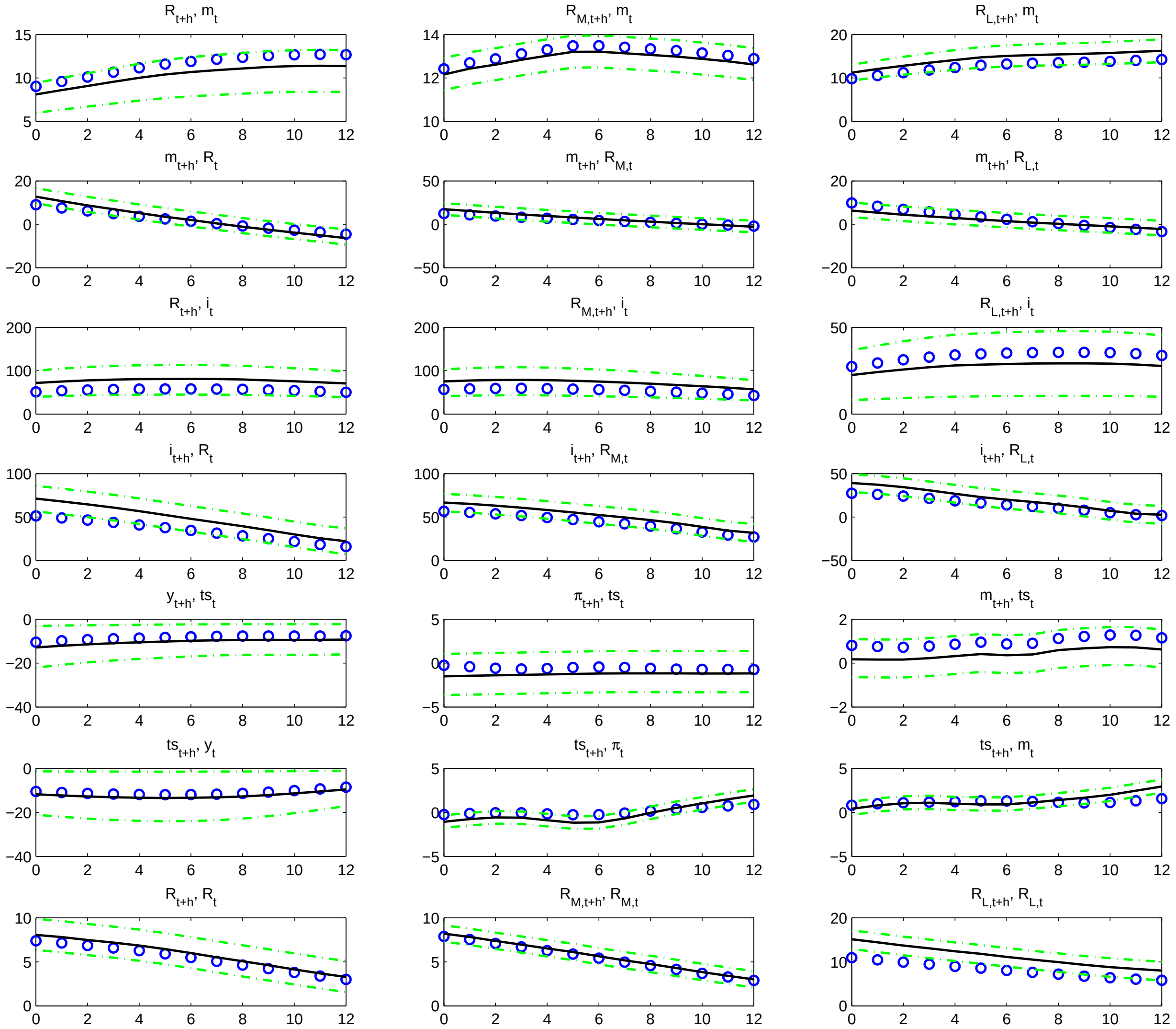
Legend: Prior distributions are indicated by dashed black lines.

Figure 3: Model and empirical cross-covariance functions



Legend: This plot shows the cross-covariance functions of series in log-deviations. Model covariances are denoted by solid lines, and the historical data by circles. Error bands for the 10% and 90% intervals from the simulated DSGE are indicated by dotted lines.

Figure 4: Model and empirical cross-covariance functions (continued)



Legend: This plot shows the cross-covariance functions of series in log-deviations. Model covariances are denoted by solid lines, and the historical data by circles. Error bands for the 10% and 90% intervals from the simulated DSGE are indicated by dotted lines.

Figure 5: RMSE from out-of-sample forecasts

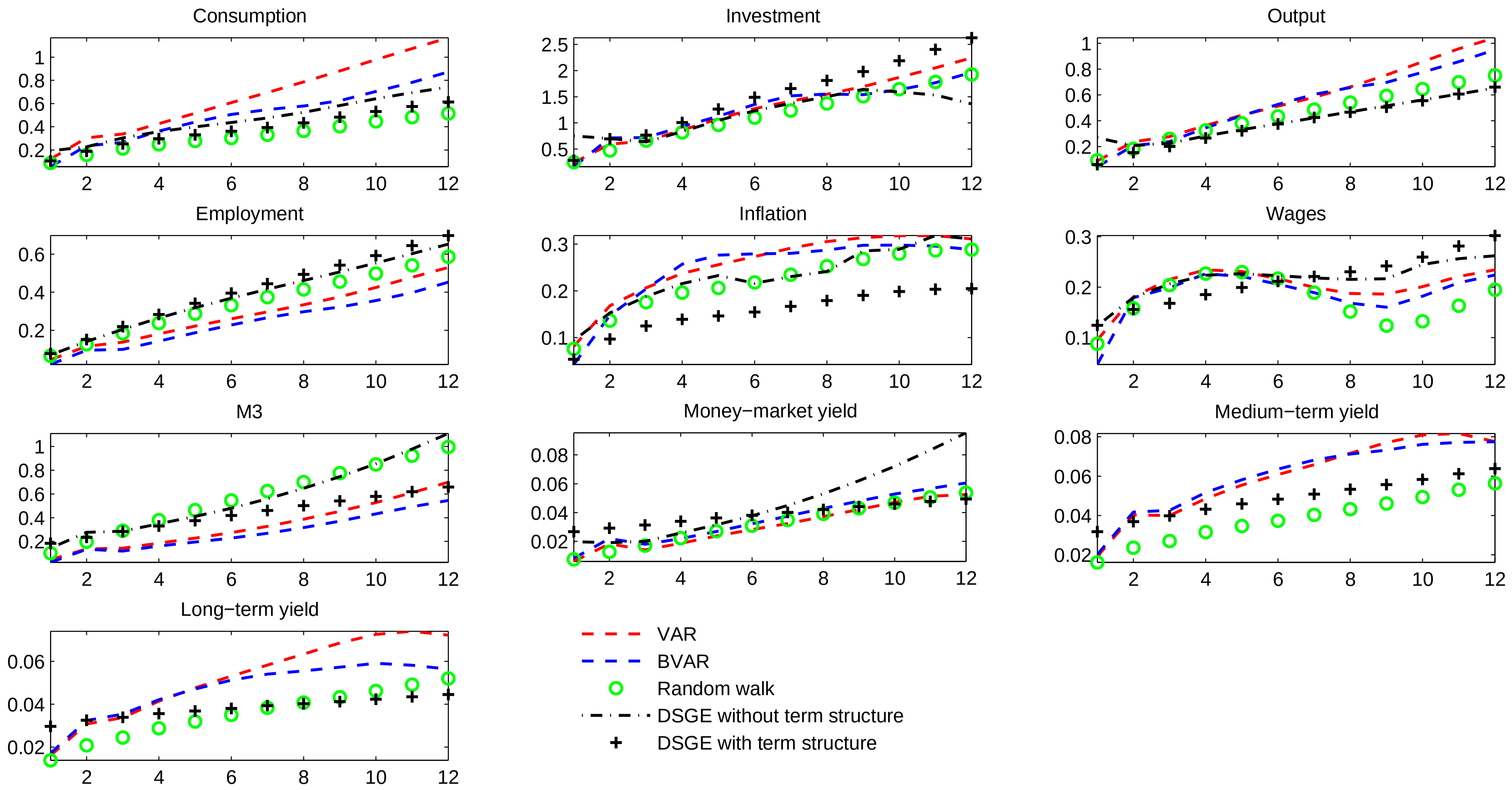


Figure 6: Impulse responses to a money demand shock

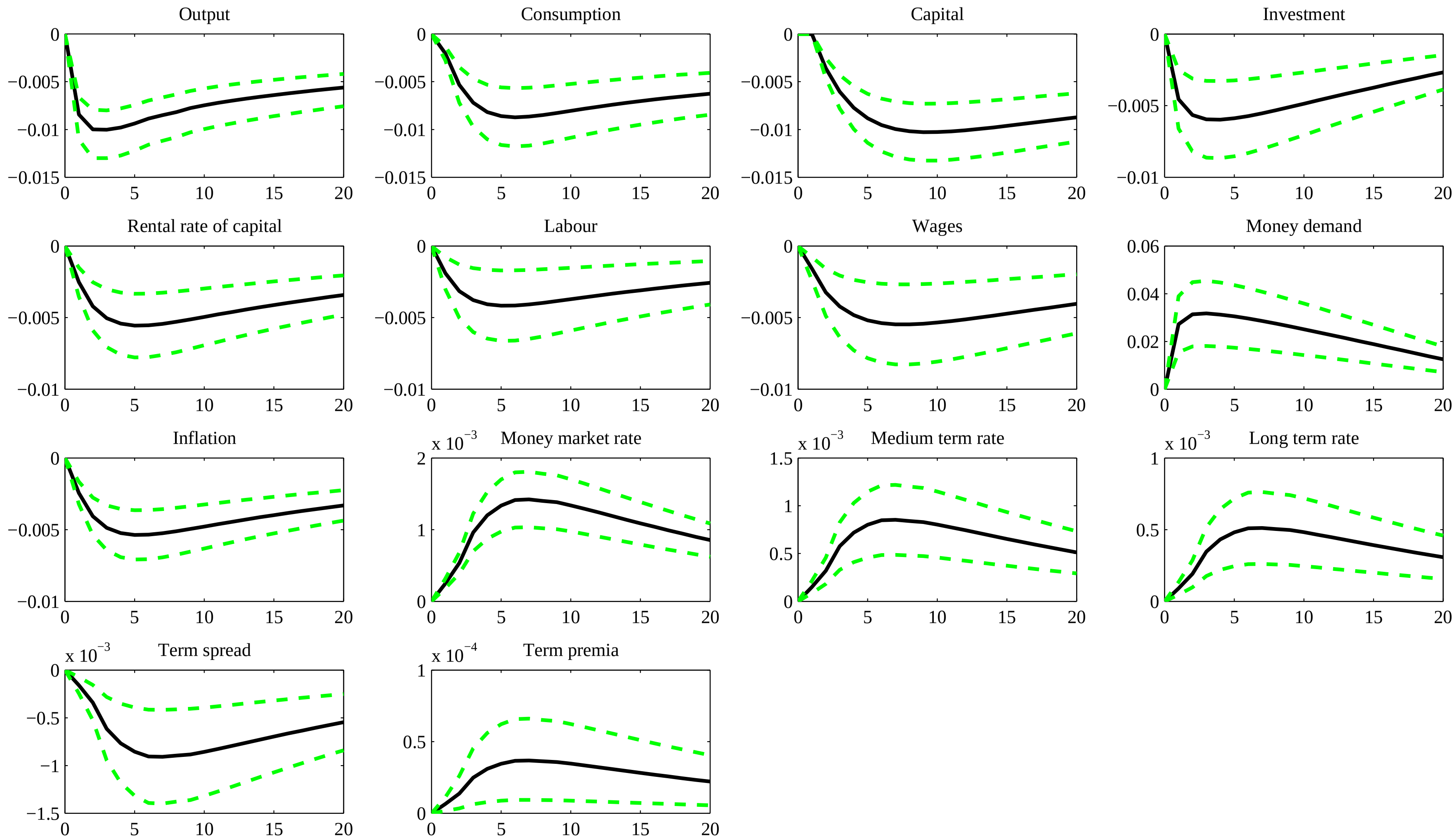


Figure 7: Impulse responses to a supply shock to medium-term bonds

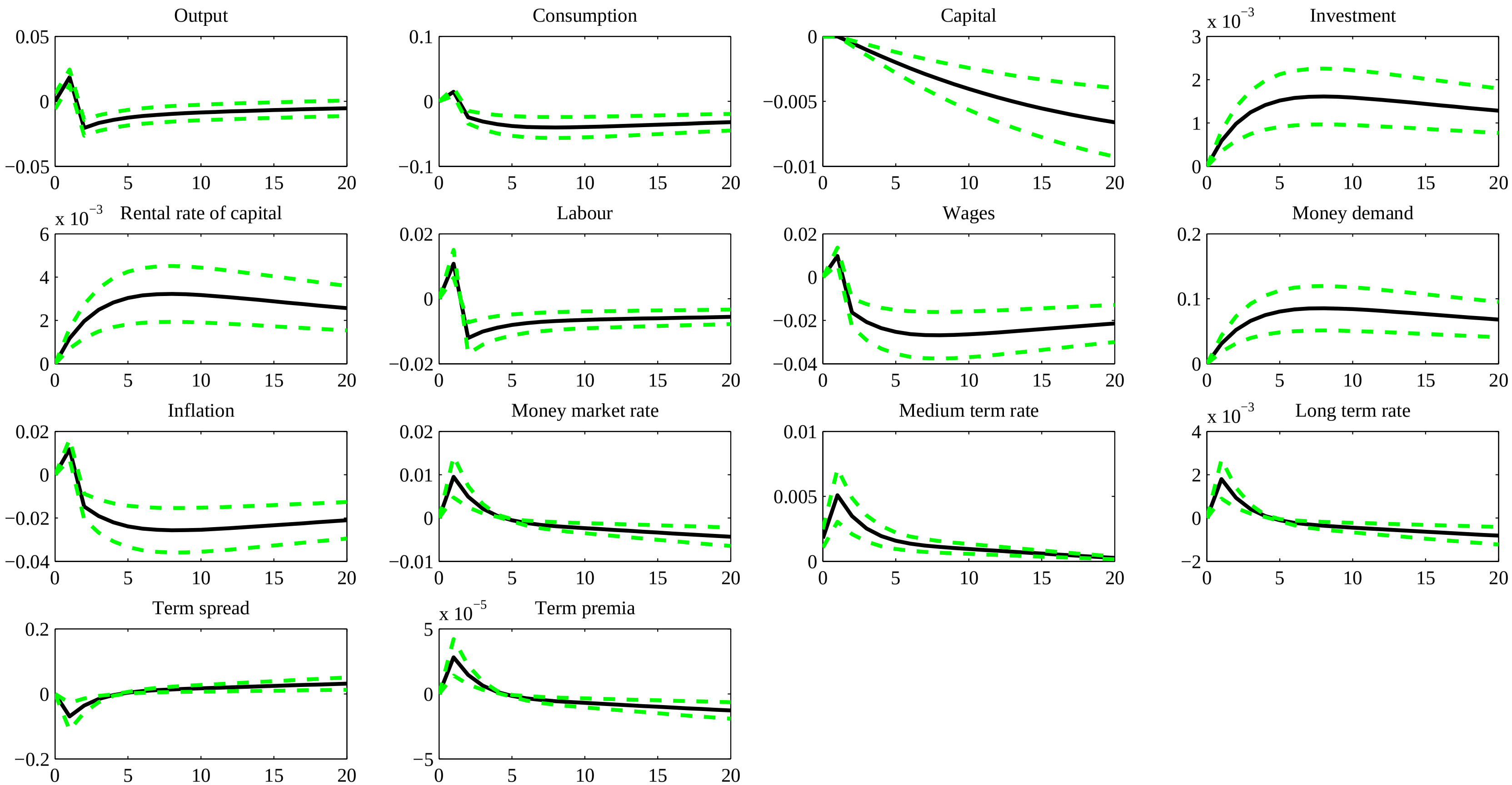


Figure 8: Impulse responses to a supply shock to long-term bonds

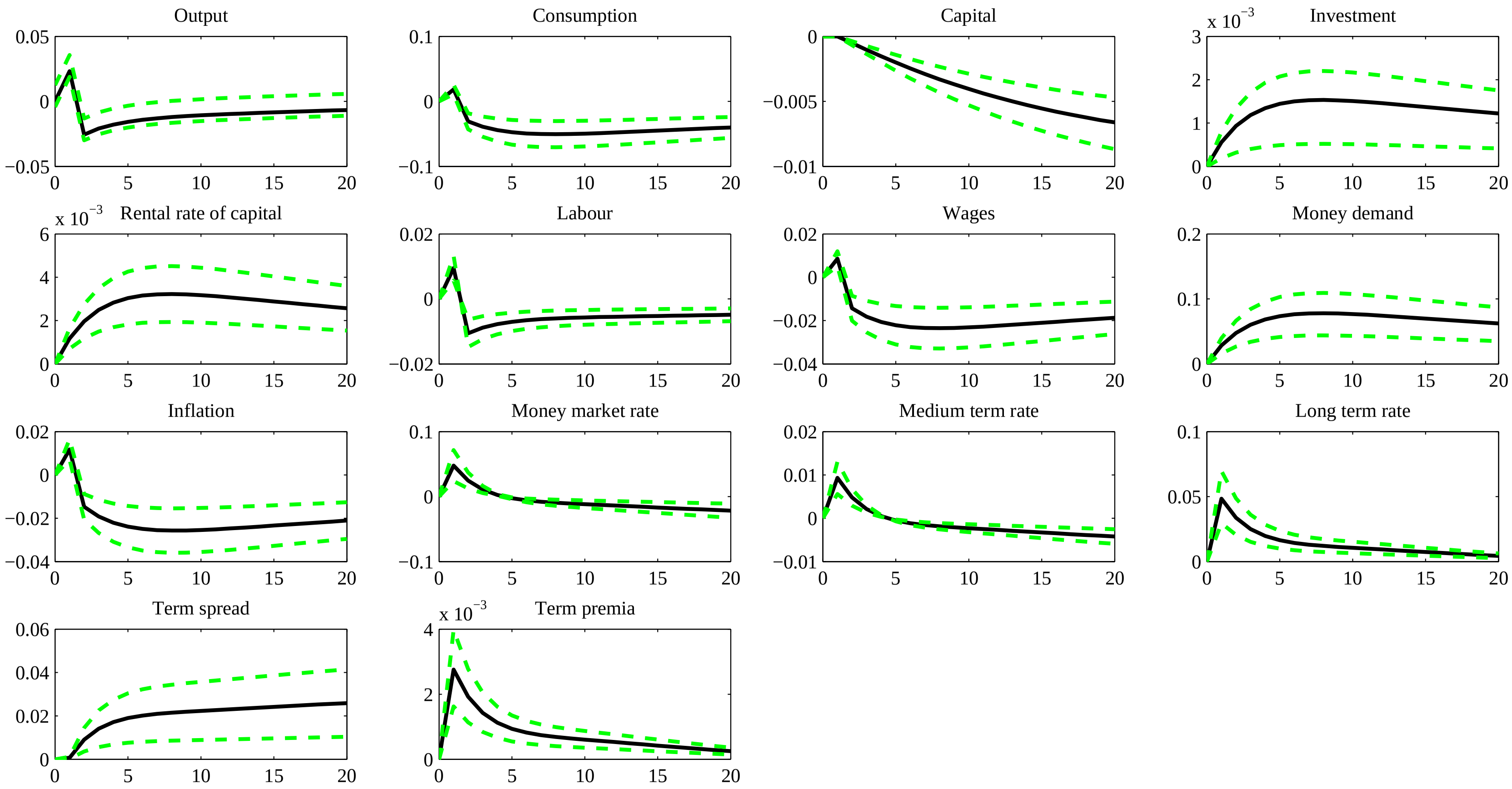
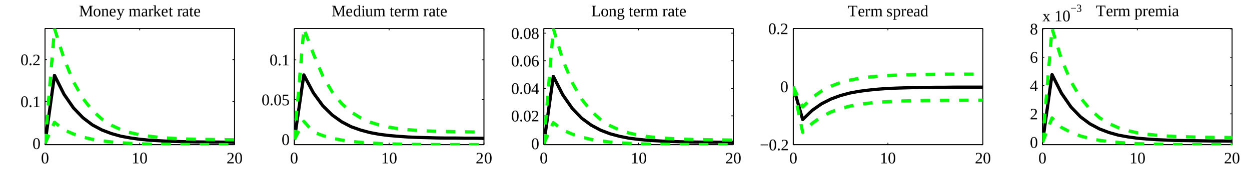
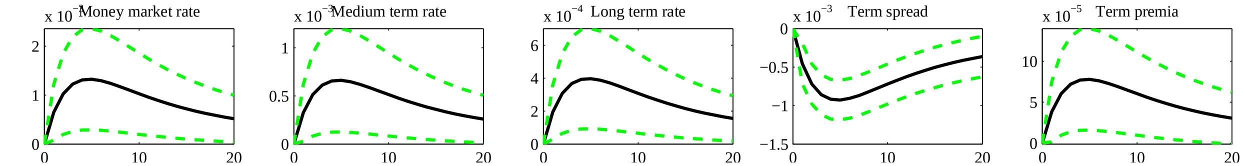


Figure 9: Impulse responses of the bond yields to selected macro shocks (1)

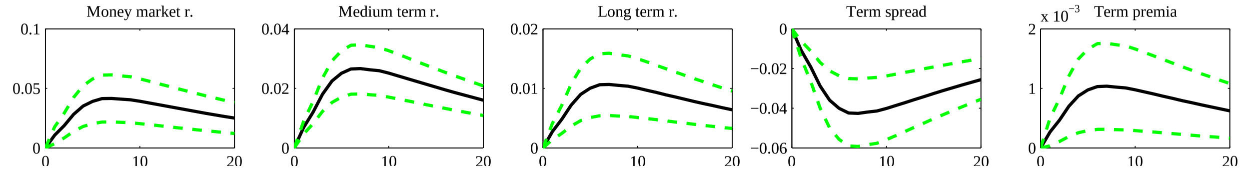
(a) Monetary policy shock



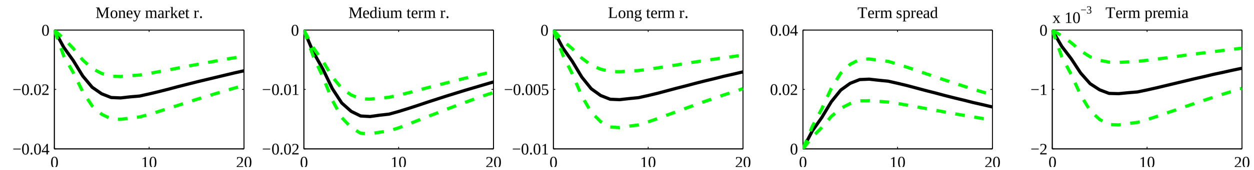
(b) Inflation target shock



(c) Preference shock



(d) Labour supply shock



(e) Shock to investment adjustment costs

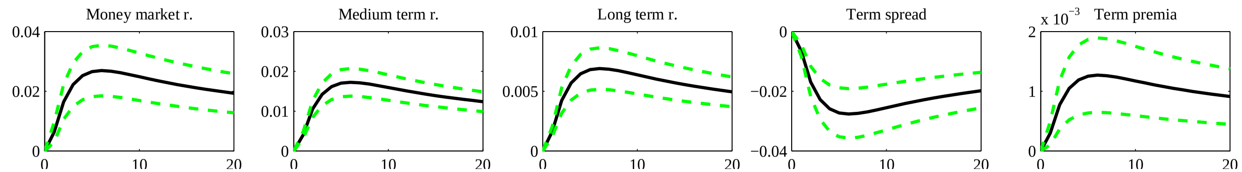
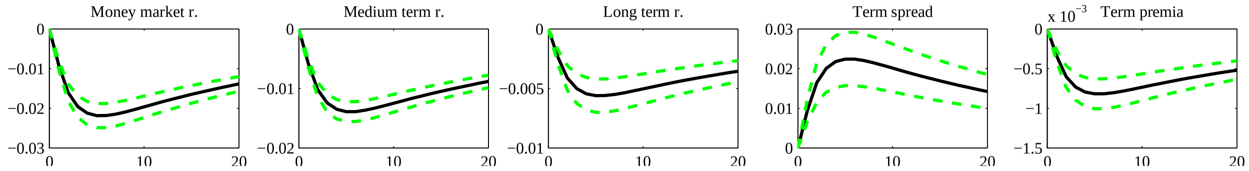
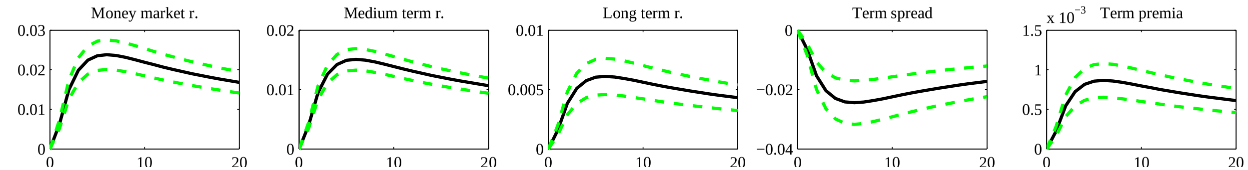


Figure 10: Impulse responses of the bond yields to selected macro shocks (2)

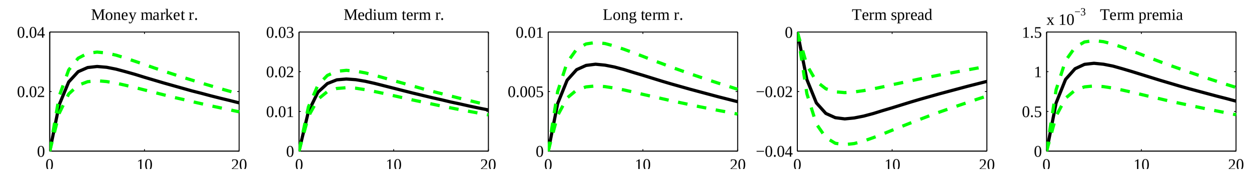
(a) Technology shock



(b) Price markup shock



(c) Wage markup shock



(d) Government spending shock

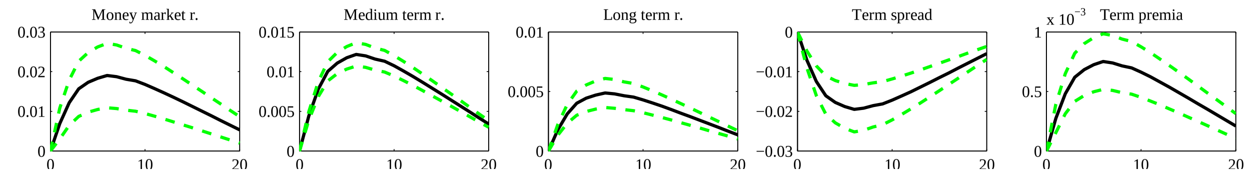


Table 1: Stylized facts

Description	Value
Consumption-GDP ratio	0.64
Real money/output ratio	0.66
Ratio of market to non-market activities	0.3
Debt-GDP ratio	0.69
Fraction of short-term debt	0.201
Fraction of medium-term debt	0.305
Fraction of long-term debt	0.494
Gross money-market rate	1.0082
Gross medium-term rate	1.0112
Gross long-term rate	1.0130

Table 2: Calibrated parameters

Description	Notation	Value
Preferences and technology		
Discount factor	β	0.992
Steady-state price markup	$(\theta_f - 1)/\theta_f$	1.2
Steady-state wage markup	$(\theta_\ell - 1)/\theta_\ell$	1.05
Capital depreciation rate	δ	0.025
Share of capital in production	α	0.36
Fixed cost	Φ	7.51
Bond adjustment costs		
Medium-term bond adjustment cost	ϕ_M	0.0006
Long-term bond adjustment cost	ϕ_L	0.007
Fiscal policy		
Fiscal policy response to nominal liabilities	ψ_1	0.92

Table 3: Parameter estimates

Description	Notation	Prior distribution			Posterior distribution			
		Distribution	Mean	Std. dev.	**Mode**	**Std. dev. Hes.**	**5%**	**95%**
Preferences and technology								
Intertemporal elasticity of substitution	σ	Normal	1	0.3	0.415	0.098	0.222	0.618
Habit formation	γ	Beta	0.6	0.2	0.488	0.075	0.336	0.648
Elasticity of money demand	χ	Normal	4.5	1.5	2.195	0.149	1.425	2.937
Labor supply elasticity	ψ	Normal	2	0.75	1.649	0.114	1.227	2.071
Adjustment cost of investment	ϕ_K	Normal	3.5	1.3	5.217	0.107	5.001	5.433
Price adjustment cost	ϕ_P	Normal	390	25	392.417	4.094	384.824	400.012
Price indexation	γ_P	Beta	0.5	0.2	0.627	0.153	0.237	1.017
Wage adjustment cost	ϕ_W	Normal	55	15	59.769	2.072	55.017	64.521
Wage indexation	γ_W	Beta	0.5	0.15	0.14	0.089	0.011	0.271
Bond adjustment costs								
Money/medium-term bond transaction cost	v_M	Normal	4.0	2	2.925	0.217	2.215	3.715
Money/long-term bond transaction cost	v_L	Normal	2.0	0.9	0.317	0.110	0.104	0.548
Monetary policy								
Monetary policy response to inflation	α_π	Normal	2	0.2	1.792	0.071	1.650	1.934
Monetary policy response to output	α_y	Normal	0.15	0.2	0.305	0.092	0.121	0.489
Monetary policy response to money	α_m	Normal	0.5	0.3	0.519	0.076	0.713	0.361
Monetary policy inertia	α_R	Beta	0.5	0.2	0.805	0.086	0.633	0.977
Autoregressive parameters								
Preferences	ρ_p	Beta	0.85	0.1	0.931	0.027	0.889	0.980
Money demand	ρ_m	Beta	0.85	0.1	0.917	0.016	0.882	0.947
Labour supply	ρ_ℓ	Beta	0.85	0.1	0.928	0.023	0.895	0.981
Investment	ρ_i	Beta	0.85	0.1	0.921	0.018	0.885	0.951
Technology	ρ_a	Beta	0.85	0.1	0.940	0.021	0.890	0.973
Price markup	ρ_P	Beta	0.85	0.1	0.912	0.037	0.841	0.984
Wage markup	ρ_w	Beta	0.85	0.1	0.951	0.028	0.897	0.995
Government spending	ρ_g	Beta	0.85	0.1	0.909	0.032	0.864	0.973
Medium-term bond supply	ρ_M	Beta	0.85	0.1	0.910	0.023	0.863	0.955
Long-term bond supply	ρ_L	Beta	0.85	0.1	0.919	0.029	0.870	0.977
Monetary policy	ρ_R	Beta	0.85	0.1	0.926	0.030	0.872	0.982
Inflation target	ρ_π	Beta	0.85	0.1	0.907	0.011	0.901	0.928
Standard deviations								
Preferences	σ_p	Inv. gamma	0.5	2	0.318	0.061	0.177	0.461
Money demand	σ_m	Inv. gamma	0.5	2	0.294	0.085	0.121	0.469
Labour supply	σ_ℓ	Inv. gamma	0.3	2	0.180	0.057	0.064	0.296
Investment	σ_i	Inv. gamma	0.4	2	0.271	0.032	0.206	0.338
Technology	σ_a	Inv. gamma	0.2	2	0.155	0.041	0.069	0.245
Price markup	σ_P	Inv. gamma	0.2	2	0.297	0.069	0.165	0.433
Wage markup	σ_w	Inv. gamma	0.2	2	0.375	0.038	0.296	0.448
Government spending	σ_g	Inv. gamma	0.4	2	0.241	0.032	0.178	0.306
Medium-term bond supply	σ_M	Inv. gamma	0.2	2	0.143	0.031	0.077	0.209
Long-term bond supply	σ_L	Inv. gamma	0.2	2	0.199	0.052	0.093	0.305
Monetary policy	σ_R	Inv. gamma	0.3	2	0.131	0.025	0.121	0.217
Inflation target	σ_π	Inv. gamma	0.2	2	0.141	0.007	0.123	0.158

Table 4: Sensitivity analysis with respect to frictions

Description	Notation	Posterior mode						
		Benchmark	No price stick. ($\phi_P = 0.001$)	No wage stick. ($\phi_W = 0.001$)	No invest. adj. cost ($\phi_K = 0.001$)	No bond-adj. costs ($v_M = v_L = 0$)	No habits ($h = 0$)	Money target ($\alpha_m = 0$)
Preferences and technology								
Intertemp. elast. of subst.	σ	0.415	0.421	0.461	0.485	0.511	0.371	0.420
Habit formation	γ	0.488	0.471	0.468	0.479	0.493	0	0.317
Elast. of money demand	χ	2.195	2.791	2.416	2.371	2.621	3.911	3.205
Labor supply elast.	ψ	1.649	1.816	1.944	1.705	1.665	1.790	1.711
Adjust. cost of invest.	ϕ_K	5.217	4.947	5.308	0.001	3.394	6.298	5.941
Price adjustment cost	ϕ_P	392.417	0.001	389.173	395.073	391.601	397.481	394.101
Price indexation	γ_P	0.627	0.591	0.704	0.613	0.608	0.715	0.664
Wage adjustment cost	ϕ_W	59.769	57.145	56.851	61.004	59.503	58.019	57.260
Wage indexation	γ_W	0.140	0.109	0.317	0.294	0.127	0.254	0.214
Bond adjustment costs								
Money/medium-term bond	v_M	2.925	2.519	3.164	3.094	0	2.741	2.991
Money/long-term bond	v_L	0.317	0.293	0.409	0.371	0	0.259	0.350
Monetary policy								
M. p. response to inflation	α_π	1.792	1.711	1.859	1.823	1.702	1.602	1.874
M. p. response to output	α_y	0.305	0.035	0.197	0.149	0.258	0.158	0.319
M. p. response to money	α_m	0.519	0.211	0.400	0.411	0.470	0.370	0
M. p. inertia	α_R	0.805	0.659	0.621	0.681	0.713	0.720	0.704
Autoreg. parameters								
Preferences	ρ_p	0.931	0.958	0.924	0.991	0.930	0.915	0.968
Money demand	ρ_m	0.917	0.903	0.915	0.941	0.909	0.906	0.955
Labour supply	ρ_ℓ	0.928	0.902	0.952	0.946	0.931	0.958	0.976
Investment	ρ_i	0.921	0.930	0.907	0.910	0.827	0.890	0.914
Technology	ρ_a	0.940	0.927	0.981	0.998	0.949	0.911	0.906
Price markup	ρ_P	0.912	0.980	0.970	0.987	0.950	0.870	0.921
Wage markup	ρ_w	0.951	0.949	0.938	0.911	0.977	0.917	0.970
Gov. spending	ρ_g	0.909	0.958	0.913	0.916	0.972	0.951	0.958
Med.-term bond sup.	ρ_M	0.910	0.914	0.921	0.899	0.899	0.917	0.919
Long-term bond sup.	ρ_L	0.919	0.939	0.897	0.890	0.916	0.901	0.884
Monetary Policy	ρ_R	0.962	0.926	0.916	0.903	0.927	0.899	0.915
Inflation target	ρ_π	0.907	0.921	0.913	0.899	0.915	0.946	0.905
Standard dev.								
Preferences	σ_p	0.318	0.416	0.305	0.450	0.396	0.519	0.418
Money demand	σ_m	0.294	0.384	0.271	0.391	0.399	0.327	0.360
Labour supply	σ_ℓ	0.180	0.180	0.198	0.247	0.187	0.185	0.190
Investment	σ_i	0.271	0.311	0.260	0.350	0.241	0.335	0.294
Technology	σ_a	0.155	0.207	0.139	0.216	0.209	0.104	0.119
Price markup	σ_P	0.297	0.471	0.301	0.480	0.351	0.338	0.341
Wage markup	σ_w	0.375	0.386	0.399	0.396	0.285	0.417	0.416
Gov. spending	σ_g	0.241	0.274	0.227	0.121	0.130	0.287	0.308
Med.-term bond sup.	σ_M	0.093	0.081	0.075	0.099	0.117	0.107	0.116
Long-term bond sup.	σ_L	0.079	0.072	0.069	0.070	0.092	0.091	0.090
Monetary policy	σ_R	0.131	0.145	0.144	0.147	0.148	0.155	0.161
Inflation target	σ_π	0.141	0.126	0.129	0.142	0.152	0.171	0.139
Log marginal likelihood		-501.114	-501.749	-501.901	-502.611	-502.690	-502.143	

Table 5: Sensitivity analysis with respect to shocks

Description	Notation	Posterior mode						
		Benchmark	No infl. target ($\sigma_\pi = 0.0001$)	No bond supply ($\{\sigma_M, \sigma_L\} = 0$)	No preference ($\sigma_p = 0.0001$)	No money demand ($\sigma_M = 0.0001$)	No price markup ($\sigma_P = 0$)	No wage markup ($\sigma_w = 0$)
Preferences and technology								
Intertemp. elast. of subst.	σ	0.415	0.494	0.471	0.385	0.439	0.520	0.452
Habit formation	γ	0.488	0.410	0.439	0.461	0.504	0.572	0.539
Elast. of money demand	χ	2.195	2.512	2.381	2.942	2.276	3.021	2.407
Labor supply elast.	ψ	1.649	1.720	1.891	1.625	2.019	2.201	2.153
Adjust. cost of invest.	ϕ_K	5.217	5.509	2.039	2.586	5.104	7.940	7.528
Price adjustment cost	ϕ_P	392.417	390.821	388.309	394.051	391.305	390.943	393.741
Price indexation	γ_P	0.627	0.513	0.701	0.725	0.581	0.740	0.644
Wage adjustment cost	ϕ_W	59.769	57.394	60.391	56.593	57.104	58.991	59.472
Wage indexation	γ_W	0.140	0.231	0.127	0.118	0.258	0.092	0.097
Bond adjustment costs								
Money/medium-term bond	v_M	2.925	3.210	3.147	3.301	2.829	3.591	3.007
Money/long-term bond	v_L	0.317	0.519	0.482	0.557	0.261	0.731	0.331
Monetary policy								
M. p. response to inflation	α_π	1.792	1.803	1.837	1.711	1.720	1.612	1.788
M. p. response to output	α_y	0.305	0.410	0.482	0.283	0.303	0.251	0.290
M. p. response to money	α_m	0.519	0.559	0.620	0.418	0.499	0.490	0.338
M. p. inertia	α_R	0.805	0.773	0.851	0.724	0.691	0.703	0.762
Autoreg. parameters								
Preferences	ρ_p	0.931	0.938	0.941	0.960	0.899	0.970	0.903
Money demand	ρ_m	0.917	0.959	0.894	0.894	0.904	0.914	0.929
Labour supply	ρ_ℓ	0.928	0.900	0.883	0.924	0.958	0.973	0.964
Investment	ρ_i	0.921	0.947	0.915	0.954	0.922	0.894	0.918
Technology	ρ_a	0.940	0.985	0.879	0.904	0.969	0.863	0.960
Price markup	ρ_P	0.912	0.919	0.972	0.930	0.902	0.929	0.948
Wage markup	ρ_w	0.951	0.922	0.907	0.947	0.919	0.892	0.905
Gov. spending	ρ_g	0.909	0.954	0.988	0.972	0.977	0.881	0.947
Med.-term bond sup.	ρ_M	0.910	0.914	0.902	0.899	0.980	0.931	0.940
Long-term bond sup.	ρ_L	0.919	0.890	0.971	0.906	0.961	0.895	0.916
Monetary Policy	ρ_R	0.926	0.921	0.964	0.949	0.929	0.883	0.890
Inflation target	ρ_π	0.907	0.904	0.916	0.930	0.947	0.939	0.957
Standard dev.								
Preferences	σ_p	0.318	0.307	0.388	0.0001	0.346	0.335	0.316
Money demand	σ_m	0.294	0.289	0.375	0.326	0.0001	0.278	0.297
Labour supply	σ_ℓ	0.180	0.195	0.250	0.215	0.227	0.199	0.194
Investment	σ_i	0.271	0.283	0.329	0.259	0.382	0.305	0.289
Technology	σ_a	0.155	0.171	0	0.216	0.259	0.216	0.171
Price markup	σ_P	0.297	0.318	0.341	0.310	0.362	0	0.310
Wage markup	σ_w	0.375	0.377	0.409	0.391	0.424	0.407	0
Gov. spending	σ_g	0.241	0.262	0.327	0.239	0.285	0.299	0.281
Med.-term bond sup.	σ_M	0.093	0	0.155	0.085	0.115	0.095	0.088
Long-term bond sup.	σ_L	0.079	0	0.146	0.085	0.107	0.091	0076
Monetary policy	σ_R	0.131	0.125	0.134	0.121	0.113	0.121	0.125
Inflation target	σ_π	0.141	0.0001	0.164	0.148	0.116	0.155	0.139
Log marginal likelihood		-501.114	-507.627	-505.394	-505.926	-509.271	-506.993	-508.203

Table 6: In-sample validation of the DSGE model

	VAR(1)*	VAR(2)	VAR(3)	VAR(4)	DSGE with term structure	DSGE without term structure
Variable	*Root mean squared errors, in-sample*					
Consumption	0.103	0.054	0.041	0.035	0.061	0.059
Investment	2.103	2.125	2.136	2.144	2.137	2.128
Output	0.495	0.496	0.497	0.499	0.503	0.504
Employment	0.485	0.483	0.483	0.483	0.491	0.487
Wage	1.102	1.105	1.109	1.112	1.124	1.115
Inflation	1.353	1.355	1.358	1.360	1.412	1.420
M3	1.758	1.760	1.763	1.767	1.771	1.830
Policy rate	1.355	1.357	1.361	1.365	1.369	1.371
Medium-term rate	1.355	1.356	1.360	1.363	1.367	-
Long-term rate	1.360	1.362	1.364	1.368	1.371	-

Legend: The first part of this table reports the mean squared errors of selected variables from in-sample forecasting of the variables in log-deviations. The VAR model includes all the variables used for the Bayesian estimation of the DSGE. (*) Model selected according to likelihood criterion.

Table 7: Forecast error variance decomposition of the DSGE model

h=1	c_t	i_t	y_t	e_t	π_t	w_t	m_t	R_t	$R_{M,t}$	$R_{L,t}$
Preferences	0.55	0.07	0.38	0.14	0.01	0.10	0.02	0.06	0.09	0.10
Money demand	0.06	0.02	0.01	0.01	0.07	0.00	0.36	0.16	0.15	0.13
Labour supply	0.12	0.01	0.03	0.12	0.06	0.04	0.01	0.04	0.04	0.03
Investment	0.01	0.66	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.01
Technology	0.05	0.07	0.10	0.41	0.01	0.02	0.07	0.01	0.03	0.01
Price markup	0.00	0.01	0.01	0.00	0.74	0.09	0.05	0.02	0.03	0.08
Wage markup	0.00	0.01	0.01	0.05	0.00	0.71	0.00	0.00	0.01	0.02
Gov. spending	0.17	0.03	0.18	0.02	0.01	0.00	0.01	0.07	0.05	0.05
Bond supplies	0.02	0.00	0.14	0.00	0.04	0.00	0.19	0.12	0.15	0.18
Monetary policy	0.02	0.12	0.12	0.24	0.02	0.04	0.21	0.23	0.09	0.04
Inflation target	0.00	0.00	0.00	0.03	0.02	0.00	0.07	0.28	0.35	0.35
h=4										
Preferences	0.59	0.09	0.34	0.11	0.00	0.08	0.00	0.09	0.07	0.05
Money demand	0.05	0.01	0.01	0.00	0.05	0.00	0.27	0.14	0.14	0.16
Labour supply	0.11	0.00	0.06	0.33	0.07	0.14	0.00	0.05	0.04	0.02
Investment	0.01	0.59	0.01	0.02	0.04	0.00	0.00	0.04	0.00	0.00
Technology	0.02	0.03	0.10	0.26	0.00	0.19	0.02	0.00	0.03	0.02
Price markup	0.00	0.01	0.03	0.00	0.55	0.01	0.04	0.01	0.03	0.05
Wage markup	0.00	0.00	0.00	0.04	0.00	0.48	0.04	0.00	0.02	0.07
Gov. spending	0.11	0.03	0.09	0.06	0.00	0.00	0.00	0.00	0.04	0.02
Bond supplies	0.00	0.00	0.12	0.00	0.00	0.00	0.15	0.10	0.09	0.11
Monetary policy	0.11	0.24	0.24	0.18	0.04	0.10	0.31	0.25	0.12	0.07
Inflation target	0.00	0.00	0.00	0.00	0.25	0.00	0.17	0.32	0.42	0.43
h=40										
Preferences	0.62	0.05	0.30	0.09	0.00	0.11	0.00	0.11	0.06	0.07
Money demand	0.07	0.00	0.00	0.00	0.11	0.00	0.27	0.13	0.15	0.18
Labour supply	0.12	0.00	0.09	0.47	0.08	0.06	0.00	0.09	0.02	0.01
Investment	0.01	0.64	0.01	0.05	0.01	0.00	0.00	0.03	0.00	0.00
Technology	0.01	0.03	0.11	0.09	0.00	0.59	0.00	0.00	0.04	0.01
Price markup	0.00	0.01	0.03	0.00	0.14	0.00	0.11	0.00	0.02	0.03
Wage markup	0.00	0.00	0.00	0.01	0.01	0.17	0.00	0.00	0.00	0.00
Gov. spending	0.00	0.01	0.11	0.16	0.00	0.00	0.00	0.00	0.01	0.01
Bond supplies	0.00	0.00	0.11	0.00	0.00	0.00	0.19	0.12	0.15	0.14
Monetary policy	0.12	0.14	0.24	0.13	0.17	0.07	0.28	0.16	0.11	0.09
Inflation target	0.00	0.00	0.00	0.00	0.47	0.00	0.15	0.36	0.44	0.46

Legend: This table reports the contribution to the forecast error variance of various shocks for the DSGE model at various horizons h.

Table 8: Posterior modes of the DSGE model without term structure

Description	Notation	Posterior mode	
		DSGE with term structure	DSGE without term structure
Preferences and technology			
Intertemporal elasticity of substitution	σ	0.415	0.720
Habit formation	γ	0.488	0.659
Elasticity of money demand	χ	2.195	5.103
Labor supply elasticity	ψ	1.649	1.412
Adjustment cost of investment	ϕ_K	5.217	6.058
Price adjustment cost	ϕ_P	392.417	371.920
Price indexation	γ_P	0.627	0.641
Wage adjustment cost	ϕ_W	59.769	55.274
Wage indexation	γ_W	0.14	0.319
Monetary policy			
Monetary policy response to inflation	α_π	1.792	1.277
Monetary policy response to output	α_y	0.305	0.184
Monetary policy response to money	α_m	0.519	0.200
Monetary policy inertia	α_R	0.805	0.799
Autoregressive parameters			
Preferences	ρ_p	0.931	0.967
Money demand	ρ_m	0.917	0.934
Labour supply	ρ_ℓ	0.928	0.942
Investment	ρ_i	0.921	0.945
Technology	ρ_a	0.940	0.973
Price markup	ρ_P	0.912	0.950
Wage markup	ρ_w	0.951	0.916
Government spending	ρ_g	0.909	0.929
Monetary Policy	ρ_R	0.926	0.910
Inflation target	ρ_π	0.907	0.885
Standard deviations			
Preferences	σ_p	0.318	0.407
Money demand	σ_m	0.294	0.351
Labour supply	σ_ℓ	0.180	0.227
Investment	σ_i	0.271	0.294
Technology	σ_a	0.155	0.182
Price markup	σ_P	0.297	0.391
Wage markup	σ_w	0.375	0.416
Government spending	σ_g	0.241	0.328
Monetary Policy	σ_R	0.131	0.105
Inflation target	σ_π	0.141	0.117

Legend: The log marginal likelihood is computed using the modified harmonic mean.

Table 9: Forecast error variance decomposition of the DSGE without term structure

	c_t	i_t	y_t	e_t	π_t	w_t	m_t	R_t
h=0								
Preferences	0.59	0.25	0.42	0.21	0.01	0.10	0.14	0.06
Money demand	0.03	0.02	0.03	0.00	0.03	0.00	0.32	0.04
Labour supply	0.12	0.11	0.12	0.18	0.03	0.04	0.09	0.16
Investment	0.11	0.26	0.02	0.04	0.00	0.00	0.07	0.01
Technology	0.12	0.13	0.07	0.47	0.01	0.00	0.14	0.05
Price markup	0.00	0.07	0.02	0.02	0.83	0.15	0.00	0.04
Wage markup	0.00	0.04	0.01	0.01	0.00	0.68	0.00	0.03
Gov. spending	0.01	0.03	0.19	0.02	0.01	0.00	0.03	0.02
Monetary policy	0.01	0.09	0.12	0.05	0.02	0.03	0.09	0.22
Inflation target	0.01	0.00	0.00	0.00	0.06	0.00	0.05	0.37
h=4								
Preferences	0.66	0.18	0.35	0.11	0.00	0.09	0.10	0.09
Money demand	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.05
Labour supply	0.14	0.15	0.11	0.45	0.09	0.14	0.04	0.08
Investment	0.06	0.48	0.06	0.06	0.02	0.01	0.02	0.03
Technology	0.07	0.12	0.30	0.28	0.00	0.11	0.16	0.04
Price markup	0.00	0.01	0.03	0.01	0.31	0.06	0.00	0.07
Wage markup	0.00	0.01	0.00	0.00	0.00	0.46	0.00	0.02
Gov. spending	0.01	0.03	0.11	0.08	0.00	0.01	0.01	0.01
Monetary policy	0.00	0.02	0.04	0.01	0.06	0.12	0.12	0.12
Inflation target	0.02	0.00	0.00	0.00	0.52	0.00	0.08	0.49
h=40								
Preferences	0.72	0.15	0.12	0.04	0.00	0.19	0.12	0.07
Money demand	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00
Labour supply	0.09	0.00	0.10	0.61	0.03	0.27	0.01	0.09
Investment	0.06	0.68	0.06	0.06	0.05	0.00	0.02	0.06
Technology	0.11	0.08	0.51	0.20	0.00	0.30	0.10	0.04
Price markup	0.00	0.06	0.03	0.01	0.16	0.02	0.00	0.05
Wage markup	0.00	0.00	0.00	0.00	0.01	0.15	0.00	0.01
Gov. spending	0.02	0.02	0.12	0.06	0.00	0.00	0.01	0.00
Monetary policy	0.00	0.01	0.06	0.02	0.04	0.07	0.15	0.05
Inflation target	0.00	0.00	0.00	0.00	0.71	0.00	0.01	0.63

Legend: This table reports the contribution to the forecast error variance of various shocks for the DSGE model without term structure at various horizons h.

Table 10: Correlations between the term spread and future output growth

(a) *Correlations*

	h=1	*h=4*	*h=12*
Data	0.351	0.272	0.180
Model	0.294	0.270	0.261

(b) *Contribution of shocks to model correlations*

	h=1	*h=4*	*h=12*
Preferences	-0.012	0.028	0.065
Money demand	0.056	0.012	0.008
Labour supply	0.025	0.025	0.032
Investment	0.078	0.076	0.085
Technology	0.018	0.014	0.016
Price markup	0.027	0.016	0.016
Wage markup	0.043	0.043	0.050
Government spending	-0.006	0.006	0.011
Medium-term bond supply	-0.024	0.028	-0.009
Long-term bond supply	0.022	0.032	-0.010
Monetary policy	0.036	0.028	-0.009
Inflation target	0.021	0.011	-0.012

Legend: Panel (a) reports the correlations between the term spread (in level) and future output growth at various horizons h. Panel (b) reports the contributions of the shocks to the simulated correlations in percentage points.